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THE

AMERICAN JOURNAL OF SCIENCE

[THIRD SERIES.]

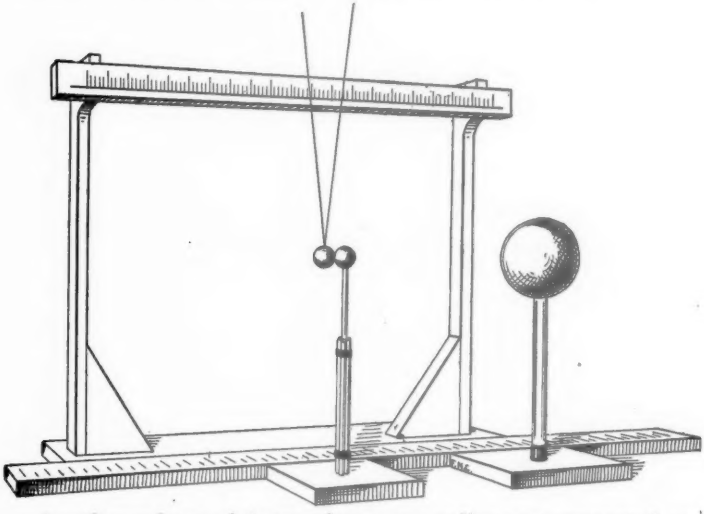
ART. XLI. — *Experiments with a Pendulum-electrometer, illustrating measurements of static Electricity in Absolute Units;* by ALFRED M. MAYER.

Description of Apparatus.—A sphere, accurately turned out of velvet cork to 1 cm. radius, with a smooth surface, was heavily gilt. A staple made of fine wire was driven into this sphere, and a very fine filament prepared from a cocoon of the silk-worm was passed through the staple and the ends of the filament were attached, at a distance of 52 cms. apart, to a support near the ceiling. In this bifilar suspension the effect of torsion is eliminated, for the twist of one length of the thread is opposed to that of the other. The vertical length of the pendulum is 364 cms. or nearly 12 feet.

A scale of millimeters, pasted on a slip of glass, is placed behind the suspending threads and 34 cms. above the center of the suspended sphere. A black band (not shown in figure) is painted along the lower edge of this scale, so that, when the line of sight is in the plane of the two threads of bifilar suspension, we see a fine white line on this black ground. This permits fine readings of deflections along the scale of millimeters.

The force pushing the pendulum from the vertical will be as the weight of the sphere and $\frac{1}{2}$ the weight of suspending thread into the sine of the angle of deflection. The weight of sphere and one half of thread is 990 mgrms., and the force of *one dyne* will give to the pendulum a deflection from the vertical of 3·4 mm. on the scale above the sphere, if we take $g = 980{\cdot}2$ cms. at Hoboken.

As not over 2° of deflection was used in the experiments, it follows that the difference between the sine of the deflection and its chord is just measurable, amounting to only $\frac{1}{6}$ mm. for an angle of deflection of 2°. The scale was inclined to the horizontal so as to coincide with the chord of 2°.



Another sphere of brass of one cm. radius was supported on a rod of glass; the latter coated, while hot, with a film of paraffine. This rod was mounted vertically on a wooden base which slid along a scale of millimeters on a table. This scale and the one before which the pendulum is deflected are so placed that when the suspended cork-sphere and the sphere on the rod are just in contact the threads of suspended sphere read 0 on the upper scale, while the vertical plane through the center of the sliding sphere reads 2 cm. on the lower scale, this being the distance apart of the centers of the spheres.

The ends of the thread, to which the gilded cork-ball is suspended, are passed through small staples in a board fastened to or near the ceiling, and are then joined together and passed around a spool fixed by a screw midway between the staples. By turning the spool the thread is wound on or off it, and thus the height of the pendulum is adjusted so that its center and that of the sphere on the glass rod are in the same horizontal line. When this adjustment has been made the head of the screw is tightened on the spool.

The sphere on the rod is charged and then slid along the scale on the table till it is in contact with the sphere of the pendulum. The charge is thus equally distributed between

the spheres: and when the sphere on the rod has been brought to 2 cm. reading on its scale, the deflection on the upper scale plus 2 cm. gives the distance of centers of spheres apart, and the force (f) in dynes in the rate of 3·4 mm. to the dyne; and $f = \frac{qq'}{D^2}$, and since $qq' = q^2$; $q = D\sqrt{f}$, as the sphere, being of 1 cm. radius, has unit capacity.

Influence of the surface of the roont and of surrounding objects on the capacity of the sphere.

If we assume (to be within bounds) that the above influences are equivalent to a sphere of 100 cms. radius, concentric with the suspended sphere, we have $C = \frac{rr'}{r'-r} = \frac{100}{99} = 1{\cdot}01$. This gives for the effect of the induction of the room in increasing the capacity of the sphere, the same as would be produced by increasing the radius of the sphere by $\frac{1}{10}$ mm.; a quantity too small to be taken into account in experiments with this apparatus, as it is not possible to form the sphere to this degree of precision. We would here remark that this apparatus is not an instrument of extreme precision, though it will measure to $\frac{1}{30}$ of a dyne, and with a sphere of pith, which has $\frac{1}{6}$ of the specific gravity of cork, it may measure to the $\frac{1}{60}$ of a dyne, if the apparatus is guarded from air currents; but this instrument gives the means of readily making electrostatic measurements before a class, and of presenting clear conceptions of the nature of these measurements.

Experiments to determine if apparatus gives the law, $f = \frac{qq'}{D^2}$.

Eight experiments are given in the following table. The first column gives the number of experiment; the second, the deflections in centimeters of the pendulum; the third, the

Exp. 1	$d = 5{\cdot}25$ $d' = 1{\cdot}15$	$D = 5{\cdot}25$ $D' = 11{\cdot}15$	$\frac{d}{d'} = 4{\cdot}56$	$\frac{D'^2}{D^2} = 4{\cdot}51$	Approx. $\frac{1}{91}$
" 2	$d = 5{\cdot}0$ $d' = 2{\cdot}4$	$D = 5{\cdot}0$ $D' = 7{\cdot}2$	" 2·08	" 2·07	" $\frac{1}{103}$
" 3	$d = 4{\cdot}8$ $d' = 2{\cdot}3$	$D = 4{\cdot}8$ $D' = 7{\cdot}0$	" 2·08	" 2·12	" $\frac{1}{52}$
" 4	$d = 3{\cdot}5$ $d' = 2\ 1$	$D = 5{\cdot}5$ $D' = 7{\cdot}1$	" 1·66	" 1·66	" $\frac{1}{60}$
" 5	$d = 2{\cdot}65$ $d' = 0{\cdot}87$	$D = 5{\cdot}65$ $D' = 9{\cdot}87$	" 3·046	" 3·051	" $\frac{1}{609}$
" 6	$d = 2\ 75$ $d' = 1{\cdot}5$	$D = 4{\cdot}77$ $D' = 6{\cdot}5$	" 1·83	" 1·85	" $\frac{1}{91}$
" 7	$d = 3{\cdot}02$ $d' = 2{\cdot}87$	$D = 4{\cdot}86$ $D' = 5{\cdot}02$	" 1·052	" 1·066	" $\frac{1}{76}$
" 8	$d = 3{\cdot}10$ $d' = 2{\cdot}94$	$D = 4\ 94$ $D' = 5{\cdot}10$	" 1·054	" 1·065	" $\frac{1}{96}$

corresponding distances of the centers of the two spheres; the fourth, the direct ratios of the deflections; the fifth, the inverse ratios of the squares of the distances between centers of spheres; the sixth, the approximations to the law of the inverse squares. By approximation we mean $\frac{d}{d'} \div \left(\frac{d}{d'} - \frac{D'}{D}\right)$.

The average approximation is quite close to the law, being $\frac{1}{106}$.

One cause of this departure from the law of the inverse squares is the mutual influence of the spheres causing a departure from uniform electrical density over their surfaces.* If we replace the cork ball by one of pith, the approximation to the law is much closer, as the distances of the spheres in the experiments are much greater. A gilded pith ball of 1 cm. radius, made of pieces of pith cemented together, weighs, with one half of the suspending filaments, only ·25 grm., about $\frac{1}{4}$ of the weight of cork ball† and filament; so that, on the pith ball pendulum, a dyne will produce a deflection of 13·3 mms. This pendulum is not suited to class experiments, as it is too readily moved by air currents, and has to be inclosed in a large cage formed of silk fastened to a light wooden frame. When this pith sphere is thus protected and suspended by an exceedingly fine fibre, it gives as close an approximation to the law of inverse squares as does the Coulomb torsion-balance. Another cause of error is the continual loss of electricity during the experiments. This error can be partly corrected by repeating as nearly as possible the first experiment and properly combining this third experiment with the first. This was not done in those given, our object having been to see how close an approximation to the law is reached by methods suited to experiments before a class. The error caused by loss of electricity can be allowed for in measurements of quantity and potential by a determination of this loss by experiments similar to those given below.

Experiments to determine the law of the loss of electricity, per minute, from a sphere of the radius of (1 *cm.*) *the unit of capacity.*

The pendulum sphere was touched by the charged sphere on the rod, and the latter remained in one position during the experiments. The deflections of the pendulum and the distances of the centers of the spheres were read every three minutes.

* On this subject see Sir W. Thomson's papers on Electr. and Mag., p. 86; and Mascart and Joubert's Electr. and Mag., vol. i, p. 153, and vol. ii, p. 173.

† The specific gravity of elder pith, in air, is ·04. This I determined by weighing a right parallelopiped cut out of this substance. The specific gravity of cork is ·24.

At the heads of the columns of following table d stands for the deflections in cms.; D, for the distances apart of the centers of spheres in cms.; f, for force in dynes; q, for units of quantity of electricity.

Times.	d	D	$f=\frac{d}{\cdot 34}$	$\sqrt{f}$	$q=D\sqrt{f}$
0 m.	3·10	5·10	9·1176	3·02	15·4020
3	3·02	5·02	8·8823	2·98	15·9596
6	2·94	4·94	8·6470	2·94	14·5236
9	2·865	4·865	8·4264	2·90	14·1085
12	2·797	4 797	8·2264	2 87	13·7674
15	2·73	4·73	8·0294	2·83	13·3859
18	2·67	4·67	7·8529	2·80	13·0760
21	2 60	4·60	7·6443	2·76	12·6960

Times.	q	Dif. 0 and 3; 3 and 6, etc.	Mean q	Loss per 3 m.	Loss per m.
0 m.	15·4020				
		·4424	15·1808	$\frac{1}{34}$	$\frac{1}{102}$
3	14·9596				
		·4360	14·7416	$\frac{1}{34}$	$\frac{1}{102}$
6	14·5236				
		·4151	14·3160	$\frac{1}{34}$	$\frac{1}{102}$
9	14·1085				
		·3411	13·9370	$\frac{1}{41}$	$\frac{1}{123}$
12	13·7674				
		·3815	13·5766	$\frac{1}{35}$	$\frac{1}{105}$
15	13·3859				
		·3099	13·2309	$\frac{1}{43}$	$\frac{1}{176}$
18	13·0760				
		·3800	12·8860	$\frac{1}{34}$	$\frac{1}{102}$
21	12·6960				

The mean loss per minute is $\frac{1}{108}$ of the charge; and the difference between the maximum and minimum measures is $\frac{1}{835}$. In Coulomb's experiments (Mem. 3^{d} 1785) this difference amounts to $\frac{1}{399}$.

The loss of electricity, as is well known, follows Newton's law of cooling; and these experiments show the operation of this law very closely.

The coefficient thus found is, however, only applicable to experiments made in similar hyrometric and barometric conditions of the air, for the coefficient varies with these conditions.

In the above experiments the barometer was at 30·069 ins.; the force of vapor ·251 ins.; and the relative humidity 31·3. Temperature of air, 73° F.

Experiments on the distribution of electricity on a cylinder, like the one experimented on by Coulomb.

In his sixth paper, of 1788,* Coulomb gives his measurements on the distribution of electricity on a cylinder with hemispheric ends. It was 30 French inches long and 2 French

* Sixième Mémoire sur l'Électricité, Mem. de l'Acad. Sci., 1788, p. 628.

inches in diameter. I made a similar cylinder of wood neatly covered with thick tin-foil. With it I made the following experiments to test the value of the pendulum-electrometer from measurements that could be compared directly with those made by Coulomb with his torsion-balance.

To do this I had first to determine the fraction of the charge lost by this cylinder per minute. This I did by transferring, at intervals of three minutes, a proof-plane from the charged cylinder to the stationary sphere of the pendulum-electrometer, and made a series of experiments similar to those given under "Experiments to determine the law of the loss of electricity, etc." It was found that the charged cylinder lost ·04 of its charge in one minute.

The following experiment, No. 9 of the series given, will show the manner of procedure in making a measure of electric density at a point on the cylinder.

Proof-plane carried from contact with middle of cylinder to stationary sphere of pendulum-electrometer gave a deflection of the pendulum of 3·55 cms., with distance of centers of spheres of 5·55 cms. $\sqrt{3{\cdot}55 \times 5{\cdot}56} = 10{\cdot}43$ = charge on middle of cylinder. After an interval of two minutes the following measure was obtained from charge of proof-plane conveyed to electrical-pendulum from contact with the end of the cylinder:

Deflection of pendulum = 6·7 cms.
Distance of centers of spheres = 8·7 cms.

$$\sqrt{6{\cdot}7 \times 8{\cdot}7} = 22{\cdot}53,\ 22{\cdot}53 + (22{\cdot}53 \times {\cdot}08) = 24{\cdot}33,$$

$$\text{and } \frac{10{\cdot}43}{24{\cdot}33} = 1 : 2{\cdot}33.$$

That is, the ratio between the electric density on the middle of the cylinder to that on the end is as 1 to 2·33.

The following measures were made in the above manner:

	Density on Middle.	Density on End.		Density on Middle.	Density on End.
1	1·00	2·42	7	1·00	2·21
2	"	2·36	8	"	2·31
3	"	2·20	9	"	2·33
4	"	2 22	10	"	2·23
5	"	2·26	11	"	2·26
6	"	2·20	12	"	2 21
	Mean = 1				2·27

Coulomb gives for the distribution on this cylinder the following ratios:

At middle of cylinder	1·00
" 2 ins. from end	1·25
" 1 in. " end	1·8
" end	2·3

The mean of our measurements gives for the ratio of densities at middle and at end of cylinder, 1 : 2·27, which is substantially the same as Coulomb's ratio of 1 : 2·3.

Measurements of Quantity and Potential.

The quantity and potential of the charge on a sphere of known radius are readily measured by the pendulum-electrometer, as shown by the following experiments.

The charged sphere, of 1 cm. radius, was brought in contact with the electric pendulum, and the force in dynes exerted on the latter was 7·058. The distance apart of centers of spheres was 7·4 cms. This gives for the quantity (Q) on the pendulum, $Q = \sqrt{7{\cdot}058} \times 7{\cdot}4 = 19{\cdot}7$ units of electricity.

As soon as the readings of the deflection of the pendulum and the distance apart of centers of spheres were obtained, the sphere on the rod, of 1 cm. radius, was removed and a charged sphere of the 4·6 cm. radius was brought opposite the charged pendulum. The deflection of the latter was now 3·5 cms.; the distance of centers of spheres, 28·5 cms., and the force of deflection in dynes, 10·29. The quantity, Q′, on larger sphere is

$$Q' = \frac{f D^2}{Q} = \frac{10{\cdot}28 \times 812{\cdot}25}{19{\cdot}7} = 424{\cdot}26$$

units of quantity.

As the potential (V) of the larger sphere is equal to the quantity (Q′) of its charge divided by its capacity (C), or radius in centimeters, we have

$$V = \frac{Q'}{C} = \frac{424}{4{\cdot}6} = 92{\cdot}2 \text{ units of potential.}$$

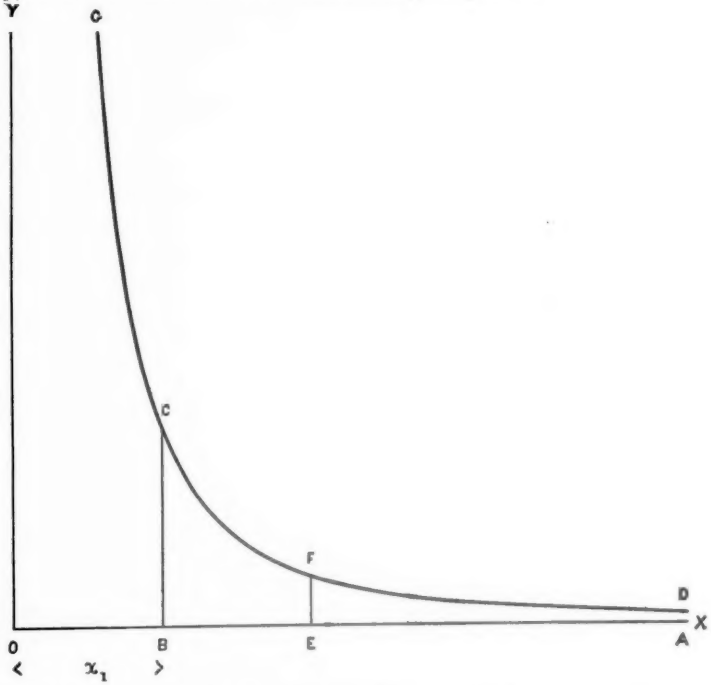
The foregoing experiments show that the pendulum-electrometer gives the law of inverse squares, serves to determine the law of dissipation of electric charge, and with it one may make measures of the electrical distribution on conductors and determine quantity and potential. In short, this simple apparatus affords an inexpensive and ready means of presenting clearly to students the nature of measurements of static electricity, and allows one to make these measures in absolute units before a class with ease and dispatch.

Stevens Institute of Technology, Hoboken, N. J.

Art. XLII.—*On Electric Potential as measured by Work;* by Alfred M. Mayer.

[Read before the National Academy of Sciences, November 10th, 1887.]

The object of this paper is to give a demonstration of the fact that the potential, $V = \frac{Q}{d} = \frac{Q}{r} = \frac{Q}{C}$; when Q=quantity, C=capacity, r=radius in cms. of charged sphere, and d=distance in cms. of centers of two charged spheres.



It occurred to me that this problem could be presented in a direct and clear manner by supposing an electrically charged sphere fixed in space with its center at O, (see fig.), and that another sphere charged with a unit of similar electricity is pushed toward O from an infinite distance, along the line OX, and that the electric strain on the moving sphere causes (without work) a vertical rod to slide out of its top in proportion as the stress between the spheres increases. As the sphere progresses along OX it will thus mark at each point of its progress the

repulsive force existing between it and the fixed sphere. The end of the sliding rod during the motion of the sphere from X towards O will have traced out the curve D F C G, whose ordinates are as the inverse squares of their distance from O.

Thus we get a trace in a manner similar to that given by the steam-engine indicator, or by one of the many instruments which draw curves, showing the varying effects of pressures, or of stresses.

The potential at any point reached in the progress of the charged body towards O = work done = resistance overcome in pushing body from infinite distance to that point; and this work done is measured by the sum of the resistances at each point of path × the length of path. But this product is equal to the *area* included between the ordinate (say B) of path, the axis of X and the curve, both indefinitely extended; or, say C B A D.

If the body has been moved from infinite distance up to E, a certain amount of work has been done; and it is to be proved that if the body has been moved from infinite distance up to B, $=\frac{1}{2}$ distance OE, that twice the amount of work has been done. In other words, it is to be proved that area C B A D is twice the area F E A D; or, generally, that such areas will vary inversely as the distance of the bounding ordinate (such as F E or C B) from O, the origin of coördinates.

The equation of the curve is

$$y=\frac{a}{x^2}$$

Area A B C D, indefinitely extended =

$$\int_{x_1}^{\infty} y\,dx=\int_{x_1}^{\infty} \frac{a}{x^2}\,dx=-a\left[\frac{1}{x}\right]_{x_1}^{\infty}=0+\frac{a}{x},\quad \therefore\ \propto \frac{1}{x}.$$

Or, area *indefinitely extended*, which represents the work, is inversely as the distance of y (the bounding ordinate of area) from O, or, $V=\frac{Q}{d}$, but also, $V=\frac{Q}{r}$, and as $V=\frac{Q}{C}$, $r=C$; r being expressed in cms.

I had supposed that the mode of presenting this problem and the demonstration based on that conception, as given in this paper, must have occurred to others before it did to me, but Professor B. O. Peirce, of Harvard University, who is better versed in the literature of the subject than I am wrote me as follows: "My experience has taught me that students who have not paid much attention to mathematics almost invariably find it difficult to get any true idea of the meaning of the word "potential" and that they value highly anything which helps to make this meaning clearer. Your graphical

illustration of the fact that in the case of two electrified spheres the potential function is a measure of work, is new to me and I feel sure that it will prove helpful to persons who already familiar with indicator diagrams, are struggling to get an idea of the use of the potential function." This opinion of Professor Peirce determined me to publish this paper.

It should be stated that Maxwell also used the indicator diagram in illustration of an electrical problem, though different from the one here considered. Section 27 of his work, "An elementary treatise on electricity," is thus headed "*Indicator diagram of electric work.* The indicator diagram, employed by Watt for measuring the work done by a steam engine, may be made use of in investigating the work done during the charging of a conductor with electricity. . . ."

Stevens Institute of Technology, Hoboken, N. J.

ART. XLIII.—*An elementary proof of the Earth's Rigidity;* by GEO. F. BECKER.

Definition of rigidity.—The term rigidity, as used in the theory of elastic bodies and in the theory of the earth, denotes any degree of resistance to change of shape. It must be confessed that the selection of this word to express this quality is not a fortunate one. In ordinary mechanics, as in ordinary life, a rigid body means one which is incapable of change of shape. Such a body would be called by elasticians *infinitely* rigid, and they attribute to every substance which shows elasticity of shape, however small, or in other words to every solid substance, the property of rigidity. Thus both india-rubber and steel are in their language rigid bodies, the difference in this respect being that the "modulus of rigidity" of steel is much greater than that of rubber. From the ambiguity of the term rigid, some geologists who were unfamiliar with his writings have been led to suppose that Sir William Thomson maintained that the earth is incapable of deformation. So far is this from the truth that Thomson was the first physicist who investigated the tidal problem on the hypothesis that the earth undergoes deformation by the attraction of the moon or sun. It is to be understood, then, that the title of this paper may be stated less concisely, but without change of meaning, as "an elementary proof of the earth's resistance to change of shape." It will not be found that the term rigidity, once understood in its special sense, leads to confusion.

Difficulty of Thomson's Problem.—No geologist would think of denying that the question of the earth's solidity is the

most important in physical geology, but as it has been treated by physicists, the subject is one of peculiar difficulty. Sir William Thomson has shown that the earth exhibits to the attractive forces of the sun and moon a resistance so great as to imply that it is solid throughout. To reach this conclusion it is necessary to determine separately the resistance to deformation which a solid sphere presents because of the mutual attraction of its parts, and the resistance due to the elastic forces which are called in play when deformation occurs.

The resistance due to gravitation is thoroughly well understood and this portion of the subject is not hard to master. On the other hand, the determination of the elastic resistance is very difficult. The general theory of the statics of elastic bodies is highly complex, and physicists are by no means agreed as to whether the general equations involve 21 or only 15 independent constants.* Both schools accept as the empirical basis of calculation Hooke's law, which experiments show to be only approximately true for small pressures, while for high pressures it is morally certain that the so called constants assume other values, and no physicist professes to be able to obtain results which are strictly accurate excepting for infinitesimal deformations.—On the basis of the general elastic theory, Lamé investigated the equilibrium of an elastic sphere by the method of spherical harmonics. There seems to be no doubt that this investigation is a masterpiece of genius. Thomson's inquiry is based upon Lamé's. He has considerably simplified the discussion, but without rendering it either short or easy; and he has applied it to the case of a homogeneous, isotropic sphere, of the size and mean density of the earth, without mutual gravitation of its parts, but subject to the attraction of a distant external body such as the sun or the moon. That even this application of Lamé's problem is laborious may be inferred from the fact that Thomson himself refers to the "tedious algebraic reductions" which he omits.

The result, so far as the earth is concerned, is an extremely simple formula for the ellipticity of an elastic sphere.

When this formula is once reached, Thomson's argument for the great effective rigidity of the earth presents no difficulty which may not be made intelligible to any geologist. It is not strange, however, that there has been some reluctance in geo-

* B. de Saint-Venant, probably the greatest elastician up to this time (he died in 1886), followed Poisson in maintaining that eolotropic elasticity involves only 15 moduluses and that isotropic elasticity involves but 1 constant. On the other hand, Green, Stokes, Thomson, and others, starting from a different view of the molecular constitution of matter, argue that 21 and 2 moduluses respectively are requisite. Lamé adopted the molecular theory which leads to uniconstant isotropy, but expresses his results by biconstant formulas. These are certainly the more convenient, for they can at once be reduced to uniconstant forms. See Todhunter's History of Elasticity.

logical circles to admit the necessity of a result the demonstration of which scarcely anyone—perhaps no one—generally classed as a geologist can follow critically.

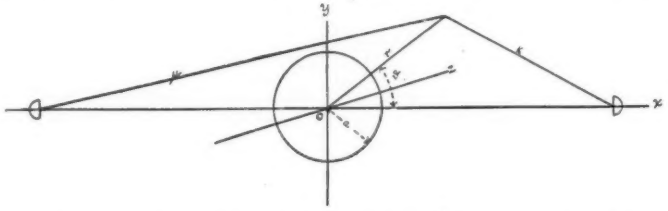
Possibility of a simplification.—It occurred to me that, since even the result of the Lamé-Thomson investigation is only an approximation for real (or finite) strain there might be some simpler way of reaching another approximation which, though less accurate, would be sufficiently close for a demonstration of the rigidity of the earth. Thomson's result is that the ellipticity of the elastic sphere, under the limitations mentioned above, is $\frac{5}{19}$ of a certain constant. If one could show that this ellipticity were, at all events, greater than $\frac{1}{4}$ of this same constant, it will appear by an examination of Thomson's argument that substantially the same results would follow.

I have succeeded in proving this inequality by a method so simple that no mathematics beyond plane trigonometry is needful to follow it. Besides presenting this proof in the most elementary possible manner to my colleagues, I shall take the occasion to follow out Thomson's argument in the way which seems best adapted to geological readers, for it appears to me certain that on some points he has been very generally misunderstood.

General character of the earth's elastic strain.—The problem of the deformation of an elastic sphere by the attraction of an external body like the moon is closely analogous to the simplest tidal problem. Suppose that the earth were always to present the same face to the moon, just as the moon presents (nearly) the same face to the earth. Then the waters would be drawn upward toward the moon to a definite ellipsoidal surface capable of accurate computation. This ellipsoid would have three unequal axes, of which the longest would be directed toward the moon, while the polar axis would be the shortest. The difference between the polar axis and the shorter of the equatorial axes would be due to the rotation of the earth-moon system, and but for this rotation the two bodies would fall together. This rotation, however, produces an elliptical flattening of the globe, while the attraction of the moon produces a distinct but superimposed elongation of the globe. It is desirable to separate these two effects and this can be done by the following device. The earth may be supposed at rest in space and subjected to the action of two bodies fixed at equal distances from it in opposite directions. If each of these bodies has half the mass of the moon, and if the distance of each of them from the earth's center is equal to the moon's real mean distance, then the deformation will be sensibly the same as that which the real moon would produce irrespective of the effects of rotation. It is the tide found on this hypothesis

which is known as the "equilibrium tide."* In the elastic problem, also the globe is supposed subjected to the attraction of two half-moons, but the resistance to deformation is supposed due solely to elastic forces instead of to gravitation.

Form of the stress.—Let the earth's center of inertia be taken as the center of coördinates; let r be the distance of any



point in space from this origin and let ϑ be the angle which r makes with the x axis. Let also μ and κ be the distances of the point from the two portions of the moon, and let M be the mass of the moon and D its mean distance. Then, by the law of gravitation, the forces acting on the point are

$$\frac{M}{2\kappa^2} \text{ and } -\frac{M}{2\mu^2}$$

and here

$$\kappa^2 = D^2\left(1 + \frac{r^2}{D^2} - \frac{2r}{D}\cos\vartheta\right);\quad \mu^2 = D^2\left(1 + \frac{r^2}{D^2} + \frac{2r}{D}\cos\vartheta\right).$$

These forces can of course be resolved in any direction by simple projections. The resulting formulas can also be simplified without substantial loss of accuracy by neglecting powers of r/D higher than the first. The distance of the moon is 60·3 times the radius of the earth, and the highest value of r^2/D^2 which can occur in this discussion is therefore only 1/3,636.

If the forces are resolved into F_r, the component coinciding in direction with the radius vector, and F_t the component at right angles to the radius it will be found that

$$F_r = \frac{Mr}{D^3}(3\cos^2\vartheta - 1) \text{ and } F_t = \frac{Mr}{D^3}\,3\sin\vartheta\cos\vartheta.$$

Or if the forces are resolved into components X, Y, Z in the directions of the axes (reckoned as usual per unit volume)

* This system of "moon and anti-moon" is that employed by Laplace, Thomson and others. Prof. G. H. Darwin has given a far more elegant method of dealing with the equilibrium tide (Encycl. Brit., Article Tides, 1888); but though his treatment is very simple, it is less adapted to a paper like this, from which it seems best to exclude the potential.

$$X=\frac{2Mx}{D^3};\quad Y=\frac{My}{D^3};\quad Z=\frac{Mz}{D^3}.$$

These, or equivalent forms, are those used in the theory of the tides and are amply accurate for most problems connected with the subject.

The total values of these forces acting on the earth are easily found. Consider first the hemisphere to the right of the yz plane. The force acting on each particle is simply proportional to its distance from the dividing plane, or to x. Now it is well known that if ξ is the distance of the center of inertia of a mass from a given plane, and if m is the mass of an elementary particle $\xi\Sigma m=\Sigma\,(mx)$. Hence the total force will be proportional to the mass of the hemisphere into the distance of its center of inertia from the origin. For the hemisphere $\xi=3a/8$ where a is the radius, and if w is the mean density, the whole force acting on the basal plane is say

$$\pi a^2X=\frac{2M}{D^3}\Sigma(mx)=\frac{2M}{D^3}\cdot\frac{3}{8}a\cdot\frac{2}{3}\pi a^3w=\frac{2M}{D^3}\frac{\pi a^4w}{4}. \qquad (1)$$

In precisely the same way one finds for the sum of the forces affecting the hemisphere which lies above the xz plane

$$\pi a^2Y=\frac{M}{D^3}\frac{\pi a^4w}{4}$$

and the symmetry of the figure shows that $Z=Y$.

The deformation of an elastic sphere of the size and mean density of the earth by a mass so small as the moon (1/83 of the mass of the earth) and at such a distance from it, is of course very minute. The most probable deformation in fact amounts to an ellipticity of about 1/10,000,000. It may be inferred therefore that the deforming stress on the plane passing through the earth's center of inertia at right angles to the direction of the moon is not very far from uniform. Were this the case the earth would be homogeneously strained, so that each elementary cube would suffer the same distortion.

Simple strain spheroid.—Suppose a cube of isotropic, homogeneous, incompressible matter (like india rubber) subjected to a uniformly distributed tensile stress in the direction of the x axis. Then by Hooke's law the elongation per unit length will be proportional to the force per unit area, say X; and if n is the constant called the modulus of rigidity, this elongation is $X/3n$. If the mass is but little strained and the volume is constant, this elongation is accompanied by a linear lateral contraction in each direction which is equal to half the elongation.*

* If the elongation of the unit cube is α and the linear lateral contraction is β, while the volume remains constant, $1=(1+\alpha)(1-\beta)^2$; and if α^2 and $\alpha\beta$ are so small as to be negligible, this reduces to $\alpha=2\beta$.

Suppose that the cube were also subjected to a compressive force Y acting at right angles to X and to a compressive force Z at right angles to each of the others. Then if the height of the cube is $2a$ and if α, β, γ are the displacements on the three axes, the cube will be elongated in the direction of x by

$$\alpha = \frac{2a\mathrm{X}}{3n} + \frac{2a\mathrm{Y}}{6n} + \frac{2a\mathrm{Z}}{6n}$$

and it will be contracted in the direction of y by

$$\beta = \frac{2a\mathrm{X}}{6n} + \frac{2a\mathrm{Y}}{3n} - \frac{2a\mathrm{Z}}{6n}$$

and γ will be symmetrical with β.

In a special case let $2\mathrm{Z}=2\mathrm{Y}=\mathrm{X}$. Then

$$\alpha = \frac{2a\mathrm{X}}{2n}; \quad \beta=\gamma=\frac{2a\mathrm{X}}{4n}.$$

Now this is precisely the effect which would be produced by a simple tensile force, P in the direction of x, unaccompanied by lateral forces, if

$$\mathrm{P} = \frac{3}{2}\,\mathrm{X}. \tag{2}$$

Consider a sphere of radius a inscribed in the cube before the application of the force P. After the mass was strained the sphere would have become an ellipsoid the major semi-axis of which would be

$$a+\frac{\alpha}{2} = a\left(1+\frac{\mathrm{X}}{2n}\right) = a\left(1+\frac{\mathrm{P}}{3n}\right)$$

and the minor semi-axes would be each

$$a-\frac{\beta}{2} = a\left(1-\frac{\mathrm{X}}{4n}\right) = a\left(1-\frac{\mathrm{P}}{6n}\right)$$

The ellipticity of this ellipsoid would be

$$e = 1 - \frac{a\left(1-\dfrac{\mathrm{P}}{6n}\right)}{a\left(1+\dfrac{\mathrm{P}}{3n}\right)} = \frac{\mathrm{P}}{2n}\cdot\frac{1}{1+\dfrac{\mathrm{P}}{3n}}$$

Here P is by supposition a force so small that its square can be neglected and thus

$$(1+\mathrm{P}/3n)^{-1} = 1-\mathrm{P}/3n$$

and hence also

$$e = \frac{\mathrm{P}}{2n} \tag{3}$$

First approximation to the earth's bodily tide.—On the hypothesis that the earth is homogeneously strained, I have only to find P of the last formula in terms of the forces applied to the earth. This has really been done in a preceding paragraph. Equations (1), (2) and (3) give

$$P = \frac{3}{2}X = \frac{3}{2}\cdot\frac{2M}{D^3}\cdot\frac{a^3w}{4} = \frac{1}{2}\tau a^3 w$$

where $\tau = 3M/2D^3$ is introduced for brevity; and if e_s is the ellipticity of the earth regarded as a simple strain ellipsoid

$$e_s = \frac{5}{20n}\tau a^3 w.$$

Character of the approximation.—No use can be made of the value e_s unless it can be shown that it is less than the true value. It has been found on the hypothesis that the stress is uniformly distributed and that the mass is incompressible, and neither supposition is strictly correct.

If one considers the true distribution of stress, it is almost self-evident that the applied force will be greater near the major axis than near the periphery of the yz section. But this can easily be proved. Suppose a slender cylinder of the elastic spheroid close to its major axis, separated from the surrounding mass as if by a diamond drill. Then the force acting upon this cylinder will be its mass into the distance of its center of inertia from the origin. But this distance is $a/2$ while the center of inertia of the hemisphere is only $3a/8$ from the origin. The cylinder will therefore be much more elongated than it would be if the sphere were homogeneously strained.

When this axial cylinder is connected with the surrounding mass, it will be held back to some extent and cannot be so much elongated as if it were free. But the fact that, when free, it is elongated by more than the average amount per unit length, proves that even when under constraint there is a tendency to greater elongation, which must be operative to some extent.

If the two lateral compressions due to the forces Z and Y are considered, it is clear that these strains will also be more intense near their respective axes than is assumed on the hypothesis of homogeneous strain. Thus the approximation underestimates the longitudinal extension and underestimates the lateral contraction; in short, it underestimates the ellipticity of an incompressible mass.

The famous result of Sir William Thomson for the case of incompressibility is, say,

$$e_r = \frac{5}{19n}\tau a^3 w = 1{\cdot}05 e_s$$

Influence of compressibility.—It will be well to consider first the effect of compressibility on the homogeneously strained spheroid already discussed. If k is the coefficient of compressibility (becoming ∞ when the mass is incompressible) the elongation of a cube of height $2a$ becomes

$$2a\,\mathrm{X}\left(\frac{1}{3n}+\frac{1}{9k}\right)$$

and the accompanying lateral contraction is

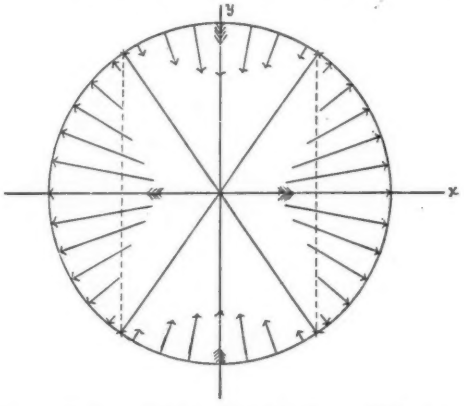
$$2a\,\mathrm{X}\left(\frac{1}{6n}-\frac{1}{9k}\right).*$$

The elongations and contractions for Y and Z are of course of the same form. If these values are introduced into the expressions for α, β, γ, it will be found that the terms in k cancel, and that the ellipticity is exactly the same as for the case of incompressibility.

To find the effect of compressibility upon the sphere when the distribution of strains is the real one, it is more convenient to deal with the polar components of the forces or

$$\mathrm{F}_r=\frac{\mathrm{M}r}{\mathrm{D}^3}\left(3\cos^2\vartheta-1\right);\ \mathrm{F}_t=\frac{\mathrm{M}r}{\mathrm{D}^3}3\sin\vartheta\cos\vartheta.$$

The latter or tangential component will have no effect upon the volume. The forces of this form will form couples tending to increase the angle which each diameter originally made with



the yz plane. Compression or dilatation will be produced by the component which is directed toward or from the center, or

* For the very simple method by which these formulas are established, see Thomson and Tait, Natural Philosophy, § 683, or Thomson's article on Elasticity, in the Encycl. Brit.

by F_r. This force vanishes when $3\cos^2\vartheta=1$ or when $\vartheta=54°\,44'$, nearly. The lines of no compressive force form a cone of two sheets, the axis of which coincides with the line connecting the two halves of the moon. Within this cone the forces F_r are directed from the center and tend to produce dilatation of the mass, and F_r is a maximum on the axis where it has the value $2\frac{Mr}{D^3}$. Between the sheets of the cone is an annular mass bounded on the surface by a zone. Within this mass the forces are directed inward, and tend to produce compression. The compressive force is maximum when $\vartheta=90$ and thus has the value Mr/D^3.

This distribution is illustrated in the diagram on page 343, where an arbitrary length is assumed as equal to the value of the force on the x-axis and the other forces are exhibited in the true proportion to it.*

When strains are small, they may be supposed to take place successively. Thus one may arrive at the distortion of a compressible sphere by supposing it first deformed as if it were incompressible, and that it then becomes compressible. If this course is adopted in the present case, the incompressible sphere would be distorted to an ellipsoid of the same volume, in which the compressive stresses exhibited in the diagram would exist, but would be inoperative. If compressibility now supervenes, it is clear that dilatation will take place along the major axis and compression at right angles to it.

General result for elastic spheroid.—Hence compressibility must increase the ellipticity which an elastic sphere assumes under a tide-generating stress. Hence also the ellipticity is always greater than $\tau w a^2/4n$, and any conclusions which can be

* It is a noteworthy fact that *all* ellipsoids of infinitesimal ellipticity and constant volume intersect the surface of the unstrained sphere at the circles of no force. One way of proving this is as follows: Let the semi-axes of the ellipse be $a(1+\delta)$ and $a(1-\delta/2)$ where δ is so small that its square can be neglected. Then, the volume being constant,

$$a^3 = a(1+\delta)\,.\,a^2(1-\delta/2)^2$$

and the equation of the ellipse is

$$\frac{x^2}{(1+\delta)^2}+\frac{y^2}{(1-\delta/2)^2}=a^2=x^2(1-2\delta)+y^2(1+\delta)$$

when this ellipse cuts the circle, $a^2=x^2+y^2$, and

$$2x^2=y^2 \text{ or } \tan^2\vartheta=2 \text{ and } \cos^2\vartheta=\frac{1}{3}$$

irrespective of the spherical value of δ.

The equipotential surfaces are hyperboloids of revolution asymptotic to the cone mentioned in the text, and the equation of the potential is simply

$$\int F_r\,dr = V = \frac{Mr^2}{2D^3}(3\cos^2\vartheta-1)$$

drawn as to the rigidity of the earth by taking as a minimum value of the distortion

$$e_s = \tfrac{1}{4}\,\frac{\tau w a^2}{n}$$

are perfectly safe.

If $3k = 5n$, as is the case for the theoretical, uniconstant, isotropic solid, and at least approximately also for glass and iron, the result reached by the beautiful, but laborious, method of Lamé and Thomson is, say

$$e_c = \frac{5}{19}\,\frac{\tau w a^2}{n}\left(1+\tfrac{2}{5}\tfrac{5}{5}\right) = 1{\cdot}09\ e_s$$

so that one is very safe indeed in taking the ellipticity as at least e_s.

Ellipticity of a fluid sphere.—Having considered the elastic resistance of the earth apart from the influence which the mutual attraction of its elements produces, it is next necessary to consider the effect of this attraction apart from the rigidity, or as if the mass were a fluid. Later it will appear how the results are to be combined so as to include both elasticity of form and attraction toward the center.

It is very easy indeed to prove that if the earth were a homogeneous, incompressible fluid of mean density 5·5, and if the attraction were directed to a single, central point; the ellipticity of the equilibrium tide would be $a\tau/g$, where g is the acceleration of pure gravitation.* It is somewhat more difficult to prove that the mutual attraction of the fluid in its deformed state would augment this ellipticity by 5/2. But these are familiar propositions of analytical mechanics, which no one doubts and which geologists are safe in accepting.

The ellipticity of an incompressible homogeneous fluid earth would then be, say,

$$e_g = \frac{5}{2}\,\frac{a\tau}{g} = 162\times 10^4\tau.$$

* The forces acting on a fluid sphere by the equilibrium theory are $\frac{M}{2\mu^2}$, $\frac{M}{2\kappa^3}$, and gravitation which is expressed by $\frac{E}{a^2}$ where E is the earth's mass. This leads to a value of the major semi-axis expressed by $r = a\left(1+\frac{Ma^3}{ED^3}\right)$. It is also readily proved that, for any ellipsoid closely approaching the sphere, the major semi-axis is $a\left(1+\frac{2}{3}e\right)$. Hence $e = \frac{3Ma^3}{2ED^3}$. (In Nat. Phil., § 804 this ellipticity is erroneously stated at twice this quantity). The ordinary meaning of g is the resultant of gravitation and centrifugal force; but on the equilibrium theory there is no rotation of the globe, and g is then equal to E/a^2. Substituting this and the value of τ, the equation becomes $e = a\tau/g$.

If the fluid supposed at first incompressible were to become compressible, it is clear that a would decrease and that g, being inversely proportional to the square of the distance from the earth's center, would increase. Thus the resistance to deformation by the attraction of the moon would increase and the deformation measured by the ellipticity would decrease. It can also be shown in detail that if the increase in density took place in any manner capable of approximate expression by Laplace's law (that the increase of the square of the density is proportional to the increase of the pressure) compressibility would decrease the ellipticity; but even infinite compressibility would only reduce the ellipticity by a moderate fraction of its value for the case of incompressibility.* Beyond a knowledge of the sense in which compressibility would affect the ellipticity of the fluid sphere it is really not worth while to inquire, for it is not at all probable that the so-called constants of elasticity, n and k, would exhibit invariability if we could experiment with pressures of hundreds of thousands of pounds to the square inch; indeed there is good evidence of great changes in rigidity even at pressures which have been experimentally applied.

Comparison of results.—In the following table I have collected the various ellipticities mentioned above with numerical expressions for spheres of the mean density of the earth, but with the rigidity of glass, brass and steel. Thomson gave figures for glass and steel, and I have added those for brass. I

* Centrifugal force is equivalent to a simple repulsion from a line, and if ω is the angular velocity, the measure of this force is $\omega^2 r$. Tide-generating force is equivalent to repulsion from a plane as appears from the manner in which it was deduced above and its measure is $2\tau x$. Hence the formulas for the two cases are convertible by the substitution of one of these forces for the other, bearing in mind that centrifugal spheroids are oblate and that tidal ellipsoids are prolate. See Nat. Phil., § 834, page 432.—If E is the mass of the earth, and if f is the ratio which the mean density of a sphere bears to its surface density, the ellipticity of a rotating spheroid in which there is a small increase in density from the surface downward, may be expressed by

$$e = \frac{5}{2}\,\frac{\omega^2 a^3}{E}\cdot\frac{1}{2(1+4(f-1))}$$

(Cf. Nat. Phil., §§ 824′ and 800). In the case of the equilibrium tide, real and apparent gravitation coincide and therefore $g = E/a^2$. Introducing also the value of τ this becomes

$$e = \frac{5}{2}\cdot\frac{\tau a}{g}\cdot\frac{1}{1+4(f-1)}$$

Similarly § 824′(2) gives for the case in which the surface density is infinitesimal as compared with the density at the center

$$e = \frac{6}{\pi^2}\cdot\frac{5}{2}\,\frac{a\tau\omega}{g} = \text{nearly } \frac{6}{10}\cdot\frac{5}{2}\cdot\frac{a\tau\omega}{g}$$

For the reasons stated in the text these formulas are of no use excepting to show that progressive increase of density decreases the ellipticity of a fluid sphere.

may note that, judging from the value of "Young's modulus," cast iron and phosphorus bronze have a rigidity nearly the same as that of brass. The rigidity of brass is from a determination by Everett. In the table n/g is the value of n in grams weight per square centimeter; e_s is the ellipticity of a homogeneously strained sphere, treated in this paper as affording a rough approximation; e_r is the ellipticity as given by Thomson's formula for the case of incompressibility; e_c is the value given by his formula for the case of compressibility if $3k = 5n$, or if isotropy involve but a single constant. Finally S and R, which will be of use presently, are given by

$$S = \frac{e_s}{e_g + e_s} \text{ and } R = \frac{e_r}{e_g + e_r}$$

ELLIPTICITIES OF ELASTIC, NON-GRAVITATING SPHEROIDS.

	n/g	e_s	e_r	e_c	S	R
Glass....	244×10^6	$235 \times 10^4\tau$	$248 \times 10^4\tau$	$257 \times 10^4\tau$	0·591	0·606
Brass....	373×10^6	$153 \times 10^4\tau$	$161 \times 10^4\tau$	$167 \times 10^4\tau$	0·485	0·498
Steel	780×10^6	$72 \times 10^4\tau$	$77 \times 10^4\tau$	$80 \times 10^4\tau$	0·311	0·322

Comparing these ellipticities with that for a fluid sphere, $e_g = 162 \times 10^4\tau$, it appears that in a globe of the size of the earth, the mutual attraction of parts is much more powerful than the elasticity of figure if the rigidity is that of glass; that these two resistances to deformation are substantially equal if the rigidity is that of brass; and that gravitation is less than half as powerful as elasticity of figure if the rigidity is that of steel.*

Combination of resistances.—The ellipticity of a deformed sphere varies directly as the applied force and inversely as the resistance. Thus if W is the resistance one may write

$$\frac{1}{e} = \frac{W}{\tau}$$

In the cases of an elastic incompressible sphere and a fluid sphere this equation takes the forms

$$\frac{1}{e_r} = \frac{19n}{5a^2w} \cdot \frac{1}{\tau} = \frac{\mathfrak{r}}{\tau} \text{ and } \frac{1}{e_g} = \frac{2g}{5a} \cdot \frac{1}{\tau} = \frac{\mathfrak{g}}{\tau}$$

where the Old English letters are introduced for brevity. In the case of a sphere in which gravitation and elasticity co-operate, $W = \mathfrak{g} + \mathfrak{r}$ and the ellipticity is expressed by

* In the first sentence of Nat. Phil., § 840, it seems to me certain that Sir William Thomson must have meant to write glass instead of steel, for he has just shown that the attraction of the moon deforms a fluid sphere much more than it does a steel sphere in which there is no mutual attraction of parts.

$$\frac{1}{e_r} = \frac{g+r}{\tau} = \frac{1}{e_g} + \frac{1}{e_r}$$

or

$$e = \frac{\tau/g}{r/g+1} = e_g \cdot \frac{e_r}{e_g+e_r} = e_g \, \mathrm{R}$$

where R is the fraction given in the table. If instead of taking Thomson's value for the ellipticity of the elastic spheroid, or e_r, my rough approximation, e_g, is substituted, e simply becomes e_gS. In the table R and S are given in decimals in order to show how far they differ. Excepting for this purpose the third decimal is of no value whatever, indeed the second decimal is also nearly if not quite worthless. Now for glass S=0·98 R and consequently is substantially identical with R.

Both R and S are in fact underestimated; for the earth is certainly compressible to some extent and, as has been shown above, compressibility increases e_r and decreases e_g. Hence the deformation of the solid globe as compared with a fluid one of the same mean density is distinctly understated in the above formulas or in other words the globe is really more rigid than the formulas imply.* The extent to which the rigidity of the earth is understated by the formulas however must be quite insignificant, unless indeed the earth contains ellipsoidal shells exhibiting a higher degree of compressibility than is shown by ordinary solids and liquids.†

Whether R or S is used in the formulas one may thus safely state that, if the earth had the same rigidity as glass, it would yield to the deforming influence of the moon and sun 3/5 as much as if it were fluid and that if it possessed the rigidity of brass it would yield 1/2 as much as if it were fluid. Even in the case of steel S=0·97 R and the difference between R and S is far within the limits of error of any knowledge which we can ever hope to reach as to the actual rigidity of the earth. Thus for steel R or S may be taken at about 1/3, and all these values, which follow from the investigations of Lamé and Thomson are also deducible from the inequality $e > \frac{1}{4}a^2\tau w$ itself deduced by the most elementary methods.

* The Rev. Osmond Fisher has attempted to reconcile the hypothesis of a fluid substratum with the effective rigidity of the earth (Physics of the Earth's Crust, 2d edition, chapter v). If I understand him correctly, he misunderstands Henry's law on which his argument is based. He seems to suppose that the amount of gas which a fluid will dissolve is proportional to the sum of the pressures of the gas and the fluid. Henry's law shows the proportionality between the pressure of the gas alone and the amount of gas which the fluid will dissolve. Water from great oceanic depths contains no more gas in solution than that from the surface.

† Thomson after calculating the effect of the compressibility of the uniconstant solid on the ellipticity of an elastic spheroid, says "we see that the compressibility of the elastic solid exercises very little influence on the result." § 837.

Apparent oceanic tides.—If the earth were a fluid of density 5·5 and the ocean rested upon the heavier liquid, both would yield to the attraction of the moon almost equally and there would be no considerable apparent tide. If the earth were a perfectly rigid mass and always turned the same exposure toward the moon, the water directly under the moon would rise $\frac{5}{9} \cdot 1\frac{3}{4}$ feet or $4\frac{3}{8}$ feet higher than it would stand at an angular distance of 90° from the moon. The solar tides are about 1/2 of the lunar tides. The actual total amplitude of the tides at oceanic ports is usually from 2 to 3 feet. Were the actual tides equal to the equilibrium tides, it would be perfectly easy to state the approximate rigidity of the earth. The real tides are greatly affected by the rotation of the earth, the obstruction of the continents, and the inequalities of the bottom. They are not static but dynamic. Nevertheless the fact that these are apparent tides shows that the earth possesses some rigidity, and the fact their amplitude is so considerable compared with the equilibrium amplitude shows that this rigidity is great. Thus if the globe were as rigid as glass, the apparent tides would be only 2/5 of the real tides or in other words perfect rigidity would then increase the apparent tides to 5/2 of their present amplitude, so that the amplitude of the tides at oceanic stations would increase to from 5 to $8\frac{1}{2}$ feet and would be much greater than the lunar equilibrium tides. If the rigidity is really that of brass, infinite rigidity would raise the oceanic tides to from 4 to 6 feet. If the earth were as strong as steel these tides would be raised by perfect rigidity to from $2\frac{1}{2}$ to $4\frac{1}{4}$ feet.

Messrs. Thomson and Darwin have examined the tidal theories and observations with especial reference to the question of rigidity. In 1888, the latter wrote, "it cannot be admitted that perfect rigidity of the earth would augment the tides in the proportion of 5 to 2, although they might perhaps be augmented in the proportion of 4 to 3."* The context shows that Darwin includes tides of short period as well as those of long period in this statement.

Rigidity of the earth.—The conditions affecting the tides of short period are so complex that no more information can be derived from them than is contained in the above quotation, which amounts to the statement that the earth's modulus of rigidity must exceed 24,400 kilograms per square centimeter by some indefinite amount. But the tides of long period must conform much more nearly to the equilibrium values than do those of short period. Were the period so long that the kinetic energy of the ebb and flow currents would be sensibly dissipated, or were the waters practically motionless at high

* Encyc. Brit., Article Tides.

water and low water, the long period tides would coincide with those of equilibrium and then observation would give a reasonably accurate value of the rigidity of the earth. Laplace supposed that the fortnightly tides did sensibly coincide with the equilibrium heights. On this hypothesis Darwin discussed the observations and found that the amplitude of the lunar fortnightly and monthly tides is about 2/3 of the equilibrium height. This would correspond to the rigidity of steel. Later however he came to the conclusion that these periods are too short to bring the waters to rest and that the result is thus vitiated.

It is certain, however, as Mr. Darwin wrote me in November, 1889, "that these tides will not be large on a rigid earth and hence the investigation remains as a general confirmation of the rigidity of the earth, without giving any quantitative evaluation of its amount."*

If the earth had the rigidity of brass the semidiurnal rise and fall of the land would be half the amplitude of the real tides and would equal the apparent tides. Were the continents uniform in lithological composition and elevation the tidal wave might pass under our feet unnoticed, as it does under a ship at sea. But it seems to me that at points near abrupt changes of density, as along the foot of a great mountain range or near the edge of a great oceanic abyss such as lies close to the Pacific Coast, a semidiurnal rise and fall of two or three feet would surely manifest itself in differential displacements.

Solidity of the earth.—The earth is thus a very rigid body. It does not follow as a matter of logical necessity that it is solid, because under certain circumstances a fluid in motion may act like a rigid mass toward certain external forces. On this subject it can only be said that, though the matter has been considered, physicists have thus far been unable to devise any system which will account for the effective rigidity of the earth as displayed in the tidal phenomena in this manner. No such explanation would be satisfactory unless the fluid were treated as viscous.

* Mr. Osmond Fisher quotes Mr. Love in the Proc. London Math. Soc., vol. xix, 1888, p. 206, as reaching the result that only the fortnightly tides can settle the question. If there is such a tide "we shall be entitled to say that the tidal effective rigidity of the earth is too great to allow us to suppose it to consist of a liquid mass covered with a thin solid crust." But, he says, "the Tidal Committee of the British Association appears to be still doubtful whether there really is an appreciable fortnightly tide." Mr. Darwin is or has been a member of the Brit. Assoc. committees on tides (excepting one to promote tidal observations in Canada) and has usually written the reports of these committees. I can find no evidence in these reports of any such doubt as is mentioned. Darwin speaks of these tides as "distinctly sensible" in Proc. R. S., Nov. 25, 1886, and as being 2/3 of the equilibrium height in Encyc. Brit., Art. Tides, 1888. That he is still confident of their existence is clear from the extract from his letter given in the text.

The average rigidity of the rocks exposed at the surface of the earth is certainly much less than that which a continuous mass of glass or brass would exhibit and there is thus a distinct difficulty in accounting for so high a rigidity as the earth evinces, even on the theory that the globe is solid. On this point, however, certain experimental results of Dr. William Hallock are very instructive. He subjected wax and paraffin to a pressure of 96,000 pounds per square inch in a horizontal steel cylinder; and on the top of these substances he placed small silver coins. The coins were forced against the tube with such violence as to leave in the steel impressions which could be felt as well as seen.* Thus substances which at one atmosphere show trifling rigidity, may develop a rigidity comparable with that of steel at pressures such as are to be found at about 15 miles below the surface of the earth.

On the other hand it is at first surprising to learn that a globe of the size of the earth and as rigid as the best drawn brass, would yield to the attraction of a distant body half as freely as if it were fluid. But it is a matter of common observation that bodies of large dimensions are not so strong as small ones in proportion to their size. Thus a bar of steel of the size of a needle held horizontally by one end does not bend even sensibly and the strain is far within the elastic limit; while a bar of the same relative dimensions, but 1000 feet long, evidently could not be supported in a similar manner. In fact, when two bodies are geometrically similar, the strength varies as the squares of the corresponding dimensions, while the mass varies as the cubes of these dimensions. When we come to deal with a mass like the earth, containing about 11×10^{20} cubic metres each weighing 5,500 kilograms, it therefore is not strange after all that it presents but a feeble resistance to external forces.

The opposition which some geologists have made to the theory of the solidity of the earth is of course based upon the hypothesis that geological phenomena cannot be accounted for on the theory of solidity. So far as the contortion of strata is concerned, there is no conflict between geology and physics. Time enters into the expression of viscosity; and the fact that the earth behaves as a rigid mass to a force which changes its direction by 360° in 24 hours is not inconsistent with great plasticity under the action of small forces which maintain their direction for ages. For a considerable number of years I have constantly had the theory of the earth's solidity in mind while making field observations on upheaval and subsidence, with the result that to my thinking, the phenomena

* This Journal, vol. xxxiv, 1887, p. 277.

are capable of much more satisfactory explanation on a solid globe than on an encrusted fluid one

The only considerable novelty in the foregoing paper is the proof that a simple strain spheroid affords an approximation to the deformation of an elastic globe sufficiently close to serve as a basis for Sir William Thomson's demonstration of the rigidity of the earth; but an endeavor has also been made to present the whole subject in a clear and elementary manner.

U. S. Geol. Survey, Washington, Feb. 1890.

ART. XLIV.—*On the Hornblende of St. Lawrence County, N. Y., and its Gliding Planes;* by GEORGE H. WILLIAMS.

A PERFECT cross-parting due to intercalated twinning lamellæ has been incidentally referred to by the writer* and by the late Professor vom Rath† as occurring on certain crystals of brown hornblende from Pierrepont, St. Lawrence County, N. Y. The phenomenon is altogether analogous to the basal parting much more commonly observed on pyroxene; and, on account of the general interest attaching to the gliding or structure planes of crystals, it seems deserving of further study.

Hornblende is one of the important silicates whose occurrence in the great belts of crystalline limestone in northern New York has rendered St. Lawrence County a well-known mineral locality. From its composition this hornblende is to be referred to *actinolite*. It presents two well marked varieties, which however differ in hardly any other respect than

	(I)	(II)
SiO_2	56·54	56·44
TiO_2	----	·11
Al_2O_3	1·10	1·77
Fe_2O_3	·69	·84
FeO	2·36	·73
MnO	----	·11
CaO	13·69	11·83
MgO	24·42	22·98
Na_2O	1·15	2·13
K_2O	----	·75
Ignition	----	2·46
	99·95	100·15

color. The one of these is green and comes principally from the neighborhood of Russell; while the other is brown and

* This Journal, III, vol. xxix, p. 486, June, 1885.

† Sitzungsber. d. niederrh. Ges. f. Natur- und Heilkunde, Juli 7, 1886.

occurs most abundantly near Pierrepont. Their chemical similarity may be gathered from the preceding analyses: I being an average of two analyses of the green variety made by Dr. W. M. Burton formerly of the Johns Hopkins University; and II, an analysis of the brown variety made by Dr. T. M. Chatard of the U. S. Geological Survey.

In habit these hornblende crystals are usually short and stout, though sometimes much elongated. Their terminal planes are few and rough, while the faces of the prismatic zone are numerous and glistening. Indeed, certain of the green crystals from Russell possess an unparalleled development of prismatic forms, showing six faces between the pinacoids whose symbols are as follows: $\infty P\bar{7}$ (170), $\infty P\bar{5}$ (150), $\infty P\bar{3}$ (130), ∞P (110), $\infty P\bar{2}$ (210), $\infty P\bar{3}$ (310).* Of these forms, all except the first have also been identified on the brown crystals from Pierrepont.

It was on certain small brown hornblende crystals of simple prismatic habit, ∞P (110) and $\infty P\bar{\infty}$ (010), from South Pierrepont that the transverse parting with parallel twinning lamellæ was first observed. Subsequent search for more material showed that, although the parting itself occurred quite frequently on both the brown and green hornblende from northern New York, twinning lamellæ parallel to the parting, which were of sufficient breadth to allow of their optical orientation, were apparently confined to such simple brown crystals as those above mentioned.†

Crystals of both the green and brown hornblende, where the parting is present without visible twinning lamellæ, often yield, on separating, a surface of high luster which allows of an exact location of the parting plane. A number of measurements of its inclination to the faces of the fundamental prism, clearly showed this plane to be parallel, not to the form usually assumed as the basal pinacoid for hornblende, as at first surmised by vom Rath and myself, but to the unit orthodome, $P\bar{\infty}$ ($\bar{1}01$), which has nearly the same inclination to the vertical axis. The angles obtained on one large crystal of brown hornblende from South Pierrepont against the four faces of the unit prism are as follows:

$\bar{1}01 : 110 = 104° 12'$
$\bar{1}01 : 1\bar{1}0 = 104° 10'$ } $104° 7' 26''$ (calc. v. Koksch.)

$\bar{1}01 : \bar{1}\bar{1}0 = 75° 49'$
$\bar{1}01 : \bar{1}10 = 75° 46'$ } $75° 52' 34''$ (calc. v. Koksch.)

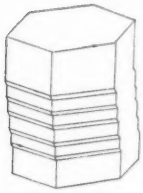
* Neues Jahrbuch für Min., etc., 1885, II, p. 175, where this hornblende was wrongly designated as *pargasite*.

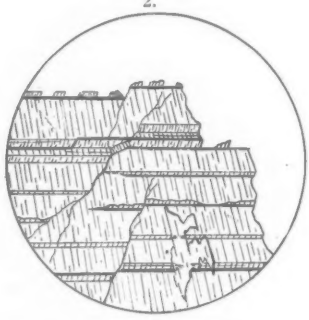
† For their kindness in willingly furnishing hornblende material for this investigation, the writer desires to express his obligation to the following gentlemen: J. H. Caswell, Esq., of New York; Messrs. C. E. Bement and Joseph Wilcox of Philadelphia, C. D. Nims of St. Lawrence County, N. Y., Dr. Whitman Cross of Washington, Prof. S. L. Penfield of New Haven, and the authorities of the U. S. Geological Survey

This result is quite in accord with the position of a similar transverse parting as determined by Cross* for hornblende in certain dioritic rocks from Brittany, and by Mügge† for analogous cases from Arendal.

Upon the simpler crystals from South Pierrepont, which show distinct twinning lamellæ parallel to the parting, this plane is itself always dull, so that no certain result can be obtained from its reflections. That its position, however, is the same as that of the above determined plane, $P\bar{\infty}(\bar{1}01)$, is proved both by the optical orientation of the lamellæ and by the angle between the prismatic faces of the lamellæ and those of the principal individual. The appearance of such a crystal is represented in fig. 1; and the transverse lamellæ, although

1. 2.





much narrower than those here depicted, are broad enough to yield distinct prismatic reflections. These gave the angles:

$$(110) : (\bar{1}\bar{1}0)' = 147° 38'$$
$$(1\bar{1}0) : (\bar{1}10)' = 147° 44'$$

while 147° 56′ 26″ is required by von Kokscharof on the supposition that the twinning axis is the normal to $P\bar{\infty}(\bar{1}01)$.

These narrow twinning lamellæ parallel to the transverse parting in the Pierrepont hornblende vary in width and are not always continuous across the crystal. Their maximum breadth is less than 0·04^{mm}, but under the microscope they nevertheless come out with a distinctness which allows of their complete optical orientation. The appearance of a portion of a thin section, cut parallel to the clinopinacoid and magnified about eighty diameters, is represented in fig. 2. In ordinary light the twinning lamellæ appear as a series of parallel bands,

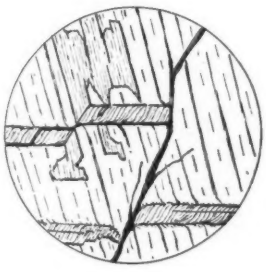
* Tschermak's Min. und Petrogr. Mitth., III, p. 386, 1881. The first observation of such a transverse parting in hornblende was made, as far as I know, by Jeremejew in 1872. Neues Jahrbuch für Min., etc, 1872, p. 405.

† Neues Jahrbuch für Min., etc., 1889, I, p. 243.

across which the cleavage lines are inclined 32° to those of the main crystals. Very often a thin film of calcite lies on one side of the twinning band; and, in some cases, this may be seen to cross from the lower to the upper side, as indicated in fig. 2. The width of these bands is very variable, as is also that of different portions of the same band. Within the hornblende are irregularly shaped intercalations of another mineral of a somewhat darker brown color than the hornblende and with a parallel extinction. It is a mica, probably phlogopite, which is regularly grown with the hornblende in such a way that their cleavages are parallel; although, in some cases, its position is wholly independent of that of the hornblende. Across large areas of this mica the twinning lamellæ do not pass, but they have evidently created more or less disturbance in the mineral where they could not produce a gliding (fig. 2). Very narrow bits of the mica are, however, displaced by the gliding of the hornblende (fig. 3).

In some cases the lamellæ die out gradually in the hornblende, while in others they terminate abruptly at a crack, beyond which they may be continued at a different level. Their microscopic character bears strong witness to the secondary and dynamic origin of these twinning bands. Within them the cleavage cracks are much more abundant than in the undisturbed hornblende substance. Along their edge the

3.



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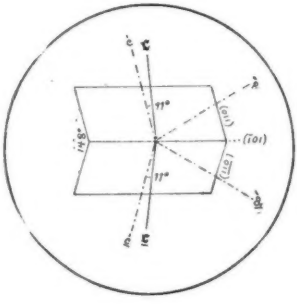


hornblende is slightly frayed out and bent, as though by a forcible shoving; and, in certain parts of the lamellæ, the little fibers are twisted across the whole width of the band, so as to produce an irregular or undulatory extinction. In still other cases, along the line of a fissure, small parts of the band are displaced from their normal direction, as shown in fig. 2.

Fig. 3 shows the highly magnified detail of lamellæ in their passage of a mica area and crack.

When viewed between crossed Nicol prisms, a section like that shown in fig. 2, displays the twinning lamellæ with a distinctness equal to that of calcite. The obtuse bisectrix, c, is inclined to the vertical axis, as indicated by the cleavage lines, about 11°. It also lies in what is usually considered the acute angle β for hornblende; and hence, while the cleavage lines of the twinning bands and the principal crystal are inclined ca. 32° to each other, their extinction directions make an angle of only 10° (fig. 4). This optical orientation is in entire accord with the measured angles as indicating $P\bar{\infty}$ ($\bar{1}01$) to be the twinning plane for these intercalated lamellæ.

Aside from the intrinsic interest attaching to the discovery of secondary transverse twinning lamellæ in hornblende, identical in character with those already well known in pyroxene, these lamellæ and their attendant parting planes are important indications of the correct crystallographic orientation of these two closely related minerals. The positions now generally employed for crystals of hornblende and pyroxene are arbitrary while they lack uniformity. I shall attempt to briefly indicate the reasons why the position commonly selected for hornblende should be so altered as to make its present orthodome $P\bar{\infty}$ ($\bar{1}01$) the basal pinacoid. No such important change should be advocated without abundant evidence in its favor, inasmuch as it modifies a long established usage on a common mineral. Nevertheless, if this usage does violence to natural relationships, such a change is warranted.

As is well known, both pyroxene and hornblende possess two planes in their orthodiagonal zones which have nearly the same inclination to the vertical axis. Assuming that the position usually adopted for pyroxene is correct, since it makes so important a direction as the gliding plane the basal pinacoid, then the arguments for reversing the common usage for hornblende are of four kinds, which are based upon

1. relative inclinations of the planes,
2. optical orientation,
3. structure planes,
4. parallel growths.

1. As they are now usually placed, the *steeper* of the two nearly equally inclined faces of the orthodiagonal zone is made the base on pyroxene, while on hornblende the *flatter* of the two is thus employed. Hence, if the positions of orthodome and basal pinacoid were reversed on hornblende, there would be uniformity established in this respect.

2. With the present orientation, the axis of elasticity c, which is nearest to the vertical axis, lies with pyroxene in the *obtuse*, but with hornblende in the *acute* angle β. If, however, such an alteration as that above mentioned were made, there would also be uniformity established here.

3. The practical identity in character of the gliding planes and secondary lamellæ in the case of hornblende and pyroxene has already been emphasized; and yet, with the present usage, we must make one of these parallel to $P\bar{\infty}$ ($\bar{1}01$), and the other parallel to 0P (001). The importance of being able to assign to them the same crystallographic symbol is at once apparent, and it has already been insisted upon by Mügge.*

4. Much the strongest argument for reversing the symbols of the orthodome and basal pinacoid of hornblende is, however, to be derived from nature's usage. As far as I have been able to extend my observations, all the many parallel growths of pyroxene and hornblende, whether original or produced by secondary paramorphism, are such that the two species have their vertical and orthodiagonal axes in common, while the basal plane of the former is as nearly as possible parallel to the orthodome of the latter. This certainly indicates the crystallographic homology of these two faces, and is alone ample reason for giving them the same symbol.

Long before gliding planes had been recognized on either pyroxene or hornblende, vom Rath described and figured parallel growths from Vesuvius like those above mentioned,† and gave them as sufficient ground for reversing the accepted symbols of one of the two minerals. He suggested that the change be made on pyroxene, but in this he has not been followed, nor should he be, since it is desirable to keep so important a face as the gliding plane for the basal pinacoid.

I have examined a large number of parallel growths of pyroxene and hornblende in rocks, and have found the lesser extinction angle for both minerals to lie on the same side of the vertical axis. This indicates an orientation similar to that observed by vom Rath.

In this connection some of the material from St. Lawrence County is particularly instructive. The brown hornblende from Pierrepont is associated with pale green salite and white albite of a lenticular habit. Parallel growths of the hornblende and salite are not uncommon. Fig. 5 represents a thin section of such a growth, cut parallel to the clinopinacoid, which is common to both minerals. The section shows that the vertical axes of both are also parallel, while the position of the extinction directions proves that the planes commonly known as the basal pinacoid for pyroxene and as the orthodome for hornblende, are nearly parallel. In the former mineral the transverse parting and twinning are well developed. In this specimen of hornblende these are absent, but we can

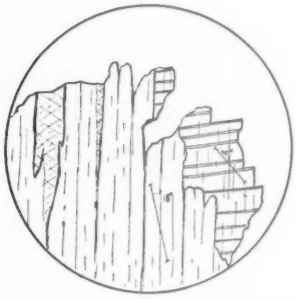
* Neues Jahrbuch für Min., etc., 1889, i, p. 244.

† Verhandl. Naturhist. Vereins d. preuss. Rheinl. u. Westfalens xxxiv, 5 Folge, Vol. iv. Neues Jahrb. für Min., etc., 1876, p. 391, pl. viii, figs. 5 and 6.

see that, if they were present, they must form nearly a continuation of the pyroxene parting. On the left of the figure inclusions of calcite in the hornblende are indicated.

Fig. 6 shows a remarkable growth of dark green hornblende from Russell, St. Lawrence County, around a crystal of pale green salite. Both crystals have their clinopinacoids parallel,

5.



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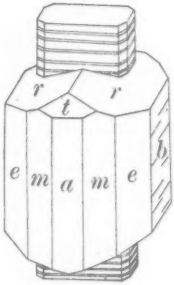


while the parting planes, which are here present in both, are as nearly as possible parallel. This specimen is about three inches in length, and belongs to the collection of Mr. Clarence Bement, in Philadelphia.

Another long crystal of green hornblende from Somerville, St. Lawrence County, loaned by Mr. Joseph Wilcox, of Philadelphia, is a twin, according to the common law (twinning-plane the orthopinacoid), and has the transverse parting well developed in both individuals parallel to the face $P\infty(\bar{1}01)$. Both surfaces give good reflections, and the angle between them was found to be 150° 10′ (calc. v. Koksch., 150° 4′). This specimen offers strong evidence against the possibility of a gliding in hornblende parallel to *both* the planes, $0P(001)$, and $P\infty(\bar{1}01)$, whose inclinations to the vertical axis are nearly the same.

In view of all this evidence we must, therefore, conclude that an alteration of the symbols for the terminal planes of hornblende is necessary to show its analogy to pyroxene; furthermore that this change must be made in accordance with the assumption that the gliding plane, now called the orthodome, $P\infty(\bar{1}01)$, is the basal pinacoid, $0P(001)$, as first suggested by Tschermak in his Lehrbuch der Mineralogie, in 1884.

Petrographical Laboratory of the Johns Hopkins University,
Baltimore, Feb., 1890.

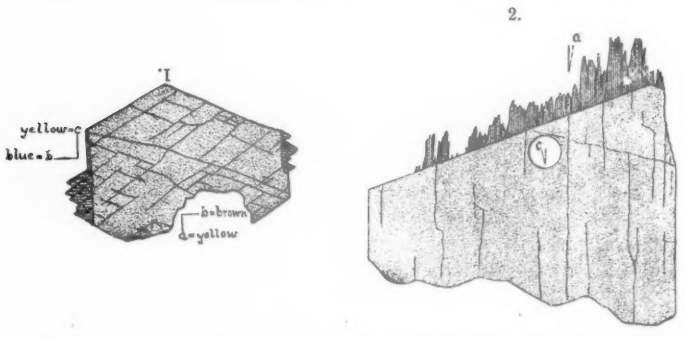
ART. XLV.—*Note on some secondary minerals of the Amphibole and Pyroxene groups;* by WHITMAN CROSS.

IN the course of the microscopical examination of some rocks from Custer County, Colorado, the writer has observed two peculiar minerals of secondary origin, one an amphibole and the other a pyroxene, which are of interest on account of their unusual properties, relationships and mode of formation. One of the observed minerals is a clear blue amphibole occurring as a pseudomorphic replacement of common hornblende or of augite, and also as enlargements of the same, with a pleochroism much like that of glaucophane, while the orientation of the ellipsoid of elasticity brings the variety into close relationship with the new species riebeckite. The pyroxene is of a bright green color and seems at first to be orthorhombic in crystal form, but it is thought more probable that it is related to ægirite, in which there is a close approximation to the optical orientation of an orthorhombic species.

The blue amphibole appears most prominently in a dike rock cutting sharply across upturned Archæan gneisses, and best seen at the northern base of the eruptive Rosita hills, about five miles east of the mining town of Silver Cliff. This dike rock is completely decomposed at its outcrop and the product, which is a mixture of calcite, quartz, barite, limonite, etc., with local impregnations of galena and other metallic sulphides, has been considered a mineral vein and several mining claims have been located upon it. It is known for a distance of about one mile with a course northwest to southeast. Prospect shafts on this "vein" have usually passed into a hard and apparently fresh rock at depths of less than fifty feet. This material is dense and tough, of apparent porphyritic structure, showing many bright green grains of pyroxene often more than one cm. in diameter, and smaller glistening prisms of brown hornblende, both being imbedded in a bluish gray matrix which usually makes up about half the rock mass. The microscope shows the matrix to consist of quartz and calcite with minute blue or green amphibole needles penetrating and coloring it. The pyroxene and hornblende are often regularly intergrown and these two are the only primary constituents of this rock now remaining, for there is no indication of the character of the mineral or minerals replaced by the quartz-calcite mass. This decomposition has already attacked the pyroxene grains and they rarely show crystal outlines, but the hornblende is better preserved and even the terminations are sometimes distinct.

The pyroxene appears almost colorless in thin sections and is not visibly pleochroic. In optical orientation it corresponds with diopside or augite, and chemical analysis shows it to belong to the aluminous variety. The material for analysis was obtained by dissolving the calcite cement and separating the pyroxene from quartz by the Thoulet solution. This examination was carried out by Mr. L. G. Eakins in the laboratory of the U. S. Geological Survey and yielded the following results: SiO_2 54·87, Al_2O_3 6·34, Fe_2O_3 2·88, FeO 4·61, MnO 0·14, CaO 15·87, MgO 14·47, Na_2O 0·28, H_2O 0·31,=99·77. There was a small amount of quartz attached to some of the grains, which explains the high silica percentage, and some brown hornblende with its alteration products was included with the pyroxene, but these latter impurities cannot have materially influenced the result.

The original hornblende associated with the augite is dark brown in color, strongly pleochroic, showing: a=pale yellow, b= reddish brown, c= almost chestnut-brown in rather thick sections. The angle $c : c$ is at least 13°. Small particles of the normal brown hornblende are included in the larger augite grains, usually with the c axis in common, and some of the hornblende prisms, on the other hand, are regularly intergrown with or include small augite prisms. As a rule the hornblende prisms are less than 1^{mm} in diameter and they are frequently terminated by the usual planes. The brown hornblende exhibits in nearly all crystals a more or less marked

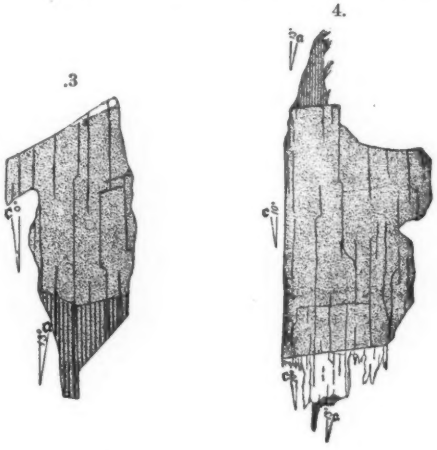


tendency to pass into a pale green or colorless amphibole with slight pleochroism and having the angle $c : c$ two or three degrees greater than in the brown variety. This green mineral seems to possess the characteristics of actinolite and it will be so designated hereafter. Besides the transformation into actinolite there is often a similar replacement of the original hornblende by a blue mineral which retains the amphi-

bole cleavage and is unquestionably a member of this group. The change to the blue amphibole may take place directly or through the intermediate actinolite, while a change of the blue into the actinolite does not occur. The blue amphibole and the the actinolite occur most prominently as enlargements of the primary hornblende crystals, being added as a rule to the clinopinacoidal or terminal planes. By means of the accompanying figures, drawn with the aid of the camera lucida, the characteristic relationships will be most clearly shown.

Fig. 1 represents a cross section of brown hornblende of entirely normal character. Upon the clinopinacoidal faces are oriented additions of blue amphibole possessing .a cleavage plainly parallel to that of the brown, and to the boundaries of the new growth. The two minerals are sharply defined by their pleochroism, being of very nearly the same pale yellow color parallel to the shorter diagonal of the prism, while the one is brown and the other a deep blue parallel to the longer diagonal.*

In fig. 2 is given a section nearly parallel to the clinopinacoid of a hornblende crystal with the blue amphibole added in flame-like forms upon the terminal planes. These two figures give the characteristic outlines assumed by the added blue amphibole in nearly all cases. The delicacy of the termina-



tions of the growths is not accurately represented by figure 2, for the ends of the spires are often made up of tufts of needles not perfectly orientated and blue fibers are attached to the

* In all figures of this article the stippled portion represents brown hornblende; the stippled with black lines, blue amphibole or allied forms; with white lines, augite; and the white areas, actinolite, unless otherwise stated.

sides in many cases. The illustrations give the form of the massive material with strictly uniform orientation. Sharp pointed spires without attached needles are seen. In fig. 2 the brown hornblende extinguishes at 9° 35′ to the left of the *c* axis, which is indicated by cleavage, while the blue extinguishes at 12° 45′ to the right. These are not maximum values, hence the section is clearly somewhat inclined to the plane of symmetry.

In fig. 3 is represented a section more nearly parallel to the clinopinacoid of a brown hornblende prism which has been partially replaced by blue amphibole at the lower end and by actinolite at the upper. In this section the brown hornblende extinguishes at 10° 40′ to the left of the cleavage line and the blue at 13° to the right. Certain cleavage lines run uninterruptedly through both minerals, and, as proven by all orientated sections, the axes *c* and *b* are plainly common to the two varieties. Fig. 4 gives a representation of a brown hornblende crystal to one end of which the blue amphibole has been added, while on the other end actinolite of pale grass-green color forms a similar extension and is itself tipped by the blue variety. The spire of blue amphibole is fringed by imperfectly oriented needles of the same substance in a manner very roughly represented by the figure and the bounding surfaces do not appear to be regular crystal planes. In optical orientation the blue portions of the two extremities are plainly identical, extinguishing at 13° to the right of the cleavage lines of the main hornblende crystal, while the latter and the added actinolite extinguish in common at 10° to the left. Fig. 5 represents a crystal of amphibole, cut nearly parallel to the clinopinacoid, in which three substances are sharply distinguished. At the lower end is the normal brown hornblende, extinguishing at 14° 30′ to the left of the axis *c*. Adjoining this is actinolite, the line between the two being straight in part and apparently representing a crystal plane. This actinolite extinguishes at 15° 30′ to the left of *c*, and while the part near the brown is grass-green the upper portion is colorless, the line between being sharp and parallel to the same apparent crystal planes as the other change. On the upper end of the crystal is an area of dark chestnut-brown color extinguishing at about 8° to the left from the cleavage lines, some of which run uninterruptedly through both the actinolite and the brown mineral. Absorption is very strong near the axis *c*, so that the angle of extinction cannot be closely measured Beyond this peculiar brown mineral there are tufts of fine blue needles some of which are orientated parallel to the vertical axis of the large crystal. They spring from the actinolite as well as from the brown amphibole, and also lie free in the calcite surrounding the crystal. While these needles do not show uniform orientation the parts of the

aggregate nearest the large crystal extinguish to the right of the vertical axis of the latter.

From the relationships observed in studying several sections of this rock the writer concludes that the actinolite of the crystal shown in fig. 5 replaces primary brown hornblende, and that the dark chestnut-brown portion is an added growth. Taken by themselves the sharp boundaries might well be considered as indicating original intergrowths of three varieties. The probable character of the added brown material will be spoken of below.

The augite of this dike rock is more strongly attacked than the hornblende by that decomposition which has resulted in the production of calcite and quartz, but it gives way to the influences which have produced the blue amphibole far less readily. Yet alteration very similar to uralitization may be

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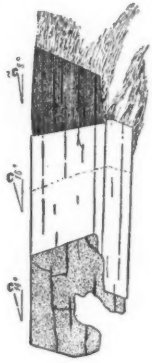

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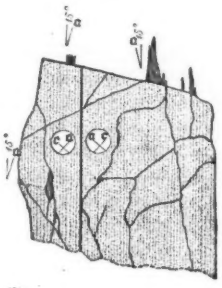


seen progressing from the irregular fissures in the augite. The fibrous product is sometimes pale green and sometimes blue, and whenever the latter is developed so as to give homogeneous optical action it can be seen to be identical in its properties with that form already described, while the green is probably actinolite.

The blue amphibole is also added to augite grains, as illustrated in figure 6. Such occurrences are comparatively rare but they are sometimes very distinct. In the case figured the augite is twinned parallel to $\infty P\bar{\infty}$ and the particles of blue amphibole added to the two parts are correspondingly orientated, as is also a small fibrous mass within the augite grain. Nearly every grain of hornblende and many of augite exhibit the blue amphibole regularly implanted upon or replacing the primary mineral in the ways represented by the figures. Fissures trav-

ersing several distinct grains will be bridged over by blue fibers which possess the crystallographic orientation of the enclosing grain. Small particles of brown hornblende included in augite grains suffer the changes noticed and the new minerals seem in some cases to have induced a similar alteration of the augite itself. The blue variety is much more common as an enlargement than is the actinolite, but they frequently occur side by side, with sharp boundaries between them.

From the study of many sections of the blue amphibole it appears as its most peculiar property that the axis of greatest elasticity, a, lies near the vertical crystallographic axis and on the opposite side from the position of c in glaucophane, common hornblende, actinolite, etc. This is clearly shown by using the quartz wedge as a compensator in the well known manner. The axis of least elasticity, c, is also in the plane of symmetry, which thus remains the plane of the optic axes as for other amphiboles. The angle $c : a$ is 13° to 15°. The optic angle is large and in consequence the optical character of the mineral could not be satisfactorily determined. Pleochroism: a=deep blue, b=purple to violet, c=pale yellow. Absorption: $a > b > c$.

The second material in which the blue amphibole has been observed occurs half a mile north of the dike above described, and is of problematic origin. In a region of fresh Archæan outcrops some prospector found a peculiar exposure and explored it by a shaft 15 feet deep. Nothing is known of the formation beyond the data afforded by this shaft. The material passed through is structurally a conglomerate, the greater part composed of pebbles less than one cm. in diameter, which are dull olive-green in color and seem macroscopically homogeneous throughout. They are imbedded in a similar green matrix which contains however many particles of feldspar, hornblende, biotite, and quartz, the gravelly debris of the adjacent gneisses. In parts of the mass are larger pebbles of gneiss or granite and a few of diorite. The surface outline of this mass is obscured but it does not extend more than a few yards from the shaft in any direction, and it seems probable that the material is the filling of a crevice or hole in the Archæan by waterworn particles. Nothing resembling it was found elsewhere. As far as the present paper is concerned it is only important to show that the rock is markedly a secondary formation and also entirely different in origin from that above described. Microscopical study shows the dull green pebbles and the green part of the groundmass to consist largely of calcite and quartz, and the green color to come from minerals of secondary origin, to be referred to again below. The grains of green or brownish hornblende of common characteristics lying in the matrix, are seen in all stages of altera-

tion to blue amphibole identical in properties with that described from the dike-rock. Additional growths are not developed in this case.

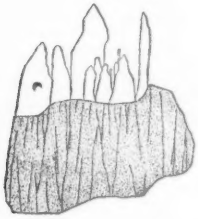
It does not seem necessary to illustrate the relationship between these amphiboles in order to establish the secondary character of the blue variety. There can scarcely be any more typical examples of the passage of one mineral into another of allied character by gradual molecular replacement, than are afforded by the change in question. It is not spoken of as paramorphosis, because identity of chemical composition is not at all probable, but the outward appearance of transition is directly comparable to the change, often seen, from brown to green hornblende. All quantitative stages of the replacement of the common hornblende by the blue may be observed to the point where the former has wholly disappeared, and beyond this to the replacement of the blue amphibole itself by calcite and quartz, or by the green pyroxene to be described.

The mineral which has been referred to as green pyroxene occurs as an alteration product of the blue amphibole, and as a new formation in small prisms and needles in feldspar, or in the secondary calcite and quartz grains. Further, it appears in the small olive-green pebbles as a decomposition product of an unknown, yellow mineral, occurring in fibrous strings similar to the forms often assumed by chlorite. Its secondary origin is also most clearly shown in a pebble of hornblende-diorite which is traversed by narrow fissures mainly filled by calcite and quartz, but also containing prisms of the green pyroxene, appearing as oriented extensions of hornblende prisms crossed by the crack, and in needles lying free in the calcite grains. The designation of this mineral as a pyroxene rests upon the visible crystallographic orientation with regard to the blue and green amphiboles, its crystal form as seen in free individuals, and its close agreement in properties with certain members of the pyroxene group. In cross sections of blue amphibole and the green mineral the latter is seen to have two cleavages of equal prominence, intersecting at an angle of about 87°, and related to the axes of the amphibole as would be normal for an intergrown pyroxene. In length sections the traces of the cleavage planes are parallel to the vertical axis, *c*. Free prisms of the mineral do not exhibit pinacoidal planes and the terminations are sharp pointed combinations of pyramids, with orthodomes in some cases at least. The color of the mineral is clear emerald-green in prisms 0·03^{mm} in thickness. The axis of greatest elasticity, a, is within a very few degrees of the vertical axis, *c*; that of least elasticity, c, is also in the plane of symmetry, assuming the orientation to be that indicated by the intergrowth with amphibole. The pleochroism is quite

strong: a=green (bluish-green in thick sections), b=clear green, c=yellow. Absorption: a >b >c. Owing to the strong absorption near a the position of this axis cannot be accurately located, and the mineral seems to extinguish parallel to its vertical axis. Sections cut normal to the prism show the optic angle to be large, but the exits of the axes are much plainer than in sections seemingly near to $\infty P\overline{\infty}$, hence the mineral is probably *negative* in optical character.

The change from blue amphibole takes place with no intermediate stage. It occurs mainly along the borders, and in less degree from fissures. In either case the alteration proceeds most rapidly from the starting point parallel to the vertical axis, producing columns of the new substance. While additions to the original amphibole grain do not appear, the pyroxene substance often assumes it proper terminal form when adjoined by calcite or quartz, and in case the latter minerals have eaten into the side of the amphibole grain the pyroxene substance may project in terminated crystal points into the area of calcite or quartz, as illustrated by fig. 7, in which the stippled area represents blue amphibole. The boundary between the minerals is in this case a cloudy zone and the amphibole is evidently giving way to calcite and quartz. There seem to be pyramidal planes on the central

7. 8.



crystal, but the others have rough faces. The section cuts nearly parallel to $\infty P\infty$, as shown by pleochroism. The needles or sharp and spine-like crystals of the same pyroxene when found free in calcite have the forms shown in fig. 8. Some of them seem to have pyramidal terminations with distinct planes (*a*), while the majority are like crystals *b*, and have apparently curved faces. Some crystals 0·4^{mm} long by 0·15^{mm} thick were isolated which are doubly terminated and then show, when lying on a prism face, the monosymmetry represented in fig. 8, *c*. This symmetry appears only where the pleochroism indicates an approach to the position of the clinopinacoid, and this fact is the strongest observable evidence for referring the mineral to the monosymmetric system. Oblique extinction in such sections cannot always be made out.

The peculiar minerals which have been described in the preceding pages are of interest from several different standpoints. In the first place, as to the identity of the varieties observed, it seems clear, either, that they represent a group of known, allied forms, occurring here under quite new and remarkable conditions, or, they constitute an equally interesting group of new varieties. The former alternative seems the more probable, and the blue amphibole is to be compared with *riebeckite*, the new species recently described by Sauer,* while the green pyroxene is apparently *ægirite*, or the closely related form *acmite*. It is also suggested that the dark brown amphibole, rarely appearing with the blue, may be *barkevicite*.

The blue amphibole agrees very closely with glaucophane in pleochroism but the colors of a and c are interchanged, corresponding to their different positions. With riebeckite the agreement in optical characters is more nearly complete. The angle $\dot{c} : a$ in the blue amphibole is 13°–15° in front of $\dot{c}$ (referred to the usual orientation of the group), while for riebeckite† $\dot{c} : a = 5°–7°$, but neither Sauer nor Rosenbusch state whether the axis a is in front of $\dot{c}$ or not. From the considerations presented below it is probable that it is inclined in the same direction as in the blue amphibole here described, and in that case the difference in orientation is but 7°–10°. Otherwise the minerals differ in intensity of color, pleochroism and absorption.‡

In his "Hülfstabellen" Rosenbusch gives the optical orientation of arfvedsonite, "$\dot{c} : c(?) = 14°$ vorn." As $b = \mathfrak{b}$ the query indicates that it may be the axis a of elasticity which is near c, and if this were true, the orientation of the blue amphibole and of arfvedsonite would be nearly identical. This orientation for arfvedsonite seems the natural one in view of the relationships to be presented.§

In the dike rock there are certain individuals of dark blue color in which absorption is so strong that they seem black when $\mathfrak{b}$ or the axis near $\dot{c}$ is parallel to the principal section of the Nicol. This dark material occurs in several places as an addition to actinolite, very much like that of the chestnut-brown mineral in fig. 5, but it is also found associated with the lighter blue amphibole in the same crystal or in separate but adjacent ones. This extremely dark variety would seem to agree fully with riebeckite, and its presence in company with

* Zeitschrift der deutsch. geol. Gesellschaft, xl, 138, 1888.

† Sauer, loc. cit. Rosenbusch, Hülfstabellen zur mikr. Mineralbestimmung, 1888.

‡ While reading the proof of this article the writer's attention was drawn to the observations of A. Lacroix on the optical properties of crocidolite (Bull. Soc. Fr. de Minéralogie, xiii, p. 10, Jan., 1890), showing that mineral to be very closely related to riebeckite and to the blue amphibole here described.

§ Lacroix has stated (Comptes Rendus, etc., cix, 39) that the amphibole from near Pike's Peak, hitherto considered to be arfvedsonite on the ground of König's analysis, has the optical orientation of riebeckite.

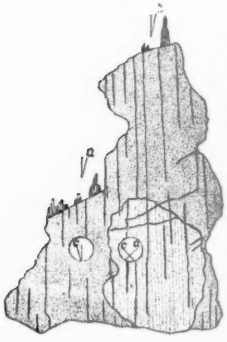
the other amphibole indicates that the latter has a somewhat different composition, though doubtless near that of riebeckite. Considering the similarity existing between these minerals and the group of soda-iron amphiboles and pyroxenes it is most natural to suspect that the dark-brown amphibole represented in fig. 5 may correspond to barkevicite, another form in which the molecule $Na_2Fe_2Si_4O_{12}$ is known to occur predominantly, according to the latest tables of Groth* and Rosenbusch.† In the crystal of fig. 5 it could not be clearly determined whether the axis near c is a or c, but the direction of extinction, being on the same side of the vertical axis as in the actinolite and hornblende, indicates that it is c.

The green pyroxene occurring in the conglomerate resembles ægirite in color, pleochroism, absorption, and optical orientation. It differs from it as the blue amphibole differs from riebeckite, in the intensity of its pleochroism and absorption, while it has a purer green color than is usual for ægirite. In the characteristic development of steep terminal planes this mineral contrasts strongly with the habit of ægirite of other occurrences, but its development is just that observed in acmite, a variety now commonly united with ægirite by mineralogists.

Repeated efforts have been made to isolate the blue amphibole and the green pyroxene for chemical analysis, but without success. The particles of pure material are so very small and are so intimately associated with brown or green hornblende or with the unknown yellowish mineral, that separations by specific gravity could not be effected. A few grains treated with hydrofluosilicic acid yielded microscopic crystals of soda and iron salts in characteristic forms.

In studying such a number of associated amphiboles and pyroxenes the writer's attention was naturally called to the character of the variations in the position of the ellipsoid of elasticity within the group of the amphiboles, and to a comparison of the variations presented by the two groups. One of the first points observed in studying the primary intergrowths of hornblende and augite in the dike rock was that the axes a and c of elasticity in the two species were always in *similar* quadrants relative to the common vertical axis, instead of in *opposite* ones as would be the case were the minerals intergrown with the basal planes of the commonly adopted orientations inclined in the same direction. Fig. 9 illus-

9.



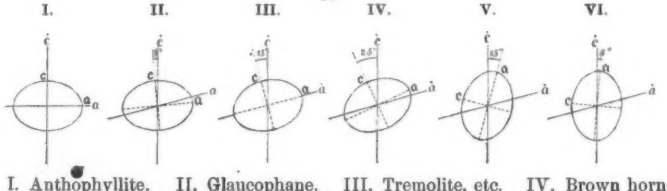
* Tabellarische Uebersicht der Mineralien, 1889.

† Hülfstabellen zur mikr. Mineralbestimmung in Gesteinen, 1888.

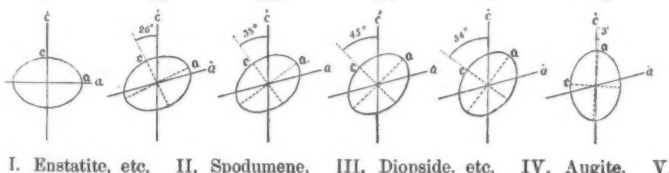
trates the orientation observed in a typical section near the clinopinacoid, showing augite surrounded by brown hornblende, with blue amphibole added to the latter. This orientation agrees fully with the observations recorded by Dr. G. H. Williams in the article preceding this, which have led him to the conclusion that in the monosymmetric amphiboles the plane $P\bar{\infty}$ of the usually adopted orientation should be taken as the basal plane 0P. As Dr. Williams clearly shows, this orientation better expresses the remarkable harmony existing between these groups in regard to several physical properties as well as to the purely crystallographical. The change has been advocated on the latter ground by various authors and the facts here presented seem to form a strong argument in the same direction.

In fig. 10 are presented a number of diagrams expressing the range of the variations in optical orientation within the two groups, the amphiboles being drawn in the new position. It will be seen at a glance that in this way the relationships of the groups are made clear. Riebeckite has been drawn in the position naturally indicated for it by analogy with ægirite and

10.



I. Anthophyllite. II. Glaucophane. III. Tremolite, etc. IV. Brown hornblende. V. Blue amphibole (Silver Cliff). VI. Riebeckite (?)



I. Enstatite, etc. II. Spodumene. III. Diopside, etc. IV. Augite. V. Augite. VI. Ægirite.

the blue amphibole of Silver Cliff. Arfvedsonite will have the position assigned to the blue amphibole or one at right angles to it, according as a or c is near $\dot{c}$. The latter position would be unique among the amphiboles. Barkevicite, if its orientation is correctly given by Rosenbusch, will be near glaucophane. Should it be proven for either of these minerals that the axis of least elasticity lies near c then we plainly cannot put that emphasis on the influence of chemical composition

in determining the optical orientation which is at once suggested by the noteworthy correspondence of riebeckite and ægirite.

The minerals ægirite, acmite, arfvedsonite and barkevicite have been described mainly from eruptive rocks rich in alkalies, such as elæolite-syenite, phonolite, leucitite, etc. Riebeckite occurs in a much altered granite, in large distinct prisms and in microlites included in feldspar. The larger free prisms are regarded by Sauer* as primary, and the latter as secondary, in origin. The occurrences here described suggest the query whether the large individuals of riebeckite in the Socotra granite may not have been originally common hornblende, which were replaced by riebeckite at the time the secondary needles were formed. The only other occurrence of probable riebeckite known to the writer is in a quartz-porphyry of Wales, described by A. Harker.† Although this rock has undergone structural metamorphosis the blue amphibole is considered to be primary riebeckite.

If the minerals which have been described be considered as ægirite, riebeckite, etc., then they appear in novel associations and were clearly formed under conditions quite different from those attending their origin in other known occurrences. Whatever the minerals in question are held to be there are many interesting points illustrated by their relationships. Perhaps none is more striking than that a pyroxene should be formed in such a manner from the decomposition of an amphibole, or that it should be formed at all, as an apparent end product of decomposition, in company with calcite and quartz. The occurrences show plainly that we have much to learn regarding the physical properties, the chemical composition, the genetic relationships, and the conditions of formation of the members of the geologically and mineralogically important groups of the amphiboles and pyroxenes.

Art. XLVI.—*On Spangolite, a new Copper Mineral;* by S. L. Penfield.

During the summer of 1889, while visiting Mr. Norman Spang of Etna, Allegheny County, Pa., my attention was called by him to a very beautifully crystallized specimen of an unknown mineral which he had obtained from a man living near Tombstone, Arizona. The original owner had a small

* Loc. cit.

† Notes on the Geology of Mynydd Mawr and the Nantle Valley, Geol. Mag., v, 1888, p. 221 and p. 455.

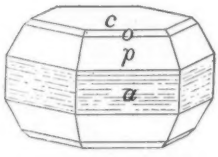
collection of minerals which he had gathered together within a radius of about two hundred miles, but he had no idea of just where he had found the specimen, though he thought it was from the Globe District. Mr. Spang had forgotten the name of the man from whom he had secured it, so that until other specimens are found uncertainty must exist about the exact locality and mode of occurrence. On expressing a desire to investigate the mineral, Mr. Spang very generously lent me the specimen and has since presented me with it, and it is now deposited in the collection of Professor Geo. J. Brush, at New Haven.

A preliminary blow-pipe examination showed that the mineral was undoubtedly a new species and essentially a hydrated sulphate and chloride of copper, and I take pleasure in not only expressing at this time my thanks to Mr. Spang for his kindness but also in naming the mineral, which as will be shown, is of unusual interest, *Spangolite* after him.

The original specimen, which was about the size of a small hen's egg, consisted of a rounded mass of impure cuprite which was mostly covered with hexagonal crystals of spangolite, associated with a few crystals of azurite and some slender pris matic crystals of a copper mineral containing chlorine, probably atacamite.

The crystallization of spangolite is hexagonal, rhombohedral. The habit of the crystals does not vary much as they all show a prominent hexagonal basal plane and a series of apparently holohedral hexagonal pyramids, which as will be shown must be taken as pyramids of the second order. Some of the crystals have the habit of fig. 1 showing a prism, which is always so dull and striated that it gives no reflection of light, associated with pyramids and a basal plane. Others are flatter, figure 2, and show a large series of pyramids which oscillate

1.



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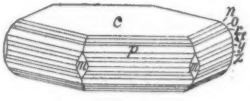


with one another, giving rise to prominent striations which run horizontally about the crystal and make the identification of the pyramids a difficult matter. On the crystals we occasionally find a prism of the first order, *m*, which is small but gives good reflections. The material which could be used for the investigation was limited, but great care was taken to select only the best and purest crystals for making the crys-

tallographic and chemical investigation. A number of small crystals were selected which were measured in the prominent pyramidal zones between the basal planes. The basal planes usually gave very good reflections of the signal but on turning the crystal on the goniometer, after the pyramids came into a position to reflect light, there usually followed an unbroken band of signals reflected from these faces owing to their striations and oscillatory combinations. In this band of reflections prominent parts could usually be located which indicated the position of distinct pyramidal faces. On measuring fifteen independent pyramidal zones on five different crystals, only one crystal was found, which we will designate as No. 1, that gave sharp reflections from the pyramidal faces; from this an angle was obtained of $c \wedge p$, $0001 \wedge 2\bar{1}\bar{1}2 = 63° 32'$. Still better results were obtained on measuring from pyramid to pyramid when the reflections of the signal are not so much disturbed by the striations and the value given below, which will be accepted as the fundamental measurement, was obtained

$$p \wedge p', 2\bar{1}\bar{1}2 \wedge 11\bar{2}2 = 53° 11' 30''$$

from which we calculate the length of the vertical axis $c = 2{\cdot}0108$.

The largest of all the crystals, which we will designate as No. 2, was fortunately so situated that it could be measured without detaching it from the specimen. It was very symmetrical and had the habit shown in fig. 1; it measured about 8^{mm} in diameter and was $5\frac{1}{2}^{mm}$ high. Five out of the six pyramidal faces p at one end of the crystal were quite perfect, being only slightly distorted by the horizontal striations. Some of the faces were so situated that reflections could not be obtained from them without detaching the crystal, but a number of very satisfactory measurements were made which are given below. The accompanying table contains a summary of the measurements which were made on the two best crystals from the faces c, 0001, O; p, $2\bar{1}\bar{1}2$, 1–2; o, $2\bar{1}\bar{1}4$, $\frac{1}{2}$–2 and m, $10\bar{1}0$, I; all of which gave sharp reflections of the signal. The measurements were made on a Fuess goniometer, using the signal and the ocular β of Websky. The one marked with an asterisk was taken as fundamental.

TABLE I.

	Crystal No. 1.	Crystal No. 2.	Calculated.
$p \wedge p'$, $2\bar{1}\bar{1}2 \wedge 11\bar{2}2$	53° 11′ 30″*	53° 13′ 45″	53° 11′ 30″
$p' \wedge p''$, $11\bar{2}2 \wedge \bar{1}2\bar{1}2$		53° 11′ 45″	"
$p'' \wedge p'''$, $\bar{1}2\bar{1}2 \wedge \bar{2}112$		53° 14′	"
$p \wedge p^{iv}$, $2\bar{1}\bar{1}2 \wedge \bar{1}\bar{1}22$		101° 43′	101° 41′
$p \wedge o^{v}$, $2\bar{1}\bar{1}2 \wedge 1\bar{2}14$	50° 48′	50° 51′	50° 51′
$p \wedge c$, $2\bar{1}\bar{1}2 \wedge 0001$	63° 32′		63° 33′ 30″
$p \wedge m$, $2\bar{1}\bar{1}2 \wedge 10\bar{1}0$	39° 4′		39° 9′

In the above table we find a very satisfactory agreement between the measured and calculated angles from which we may conclude that the measurement which we have accepted as fundamental is very nearly correct.

When all of the approximate measurements, which were obtained from fifteen different zones measuring from the basal plane above over the pyramids on the base below, are tabulated it is found that with few exceptions they fall into groups indicating the existence of a series of pyramids, among which we may safely assume the following, in addition to those which have already been mentioned: *k*, $2\bar{1}\bar{1}8$, $\frac{1}{4}$–2; *n*, $2\bar{1}\bar{1}6$, $\frac{1}{3}$–2; *r*, $6\bar{3}\bar{3}8$, $\frac{3}{4}$–2; *l*, $6\bar{3}\bar{3}7$, $\frac{6}{7}$–2; *x*, $6\bar{3}\bar{3}4$, $\frac{3}{2}$–2; *y*, $2\bar{1}\bar{1}1$, 2–2; *z*, $6\bar{3}\bar{3}2$, 3–2.

The following table contains a summary of the measurements which can be referred to the definite pyramids just mentioned.

TABLE II.

	No. of times observed.	Limiting measurements.	Average.	Calculated.
$c \wedge k$, $0001 \wedge 2\bar{1}\bar{1}8$	3	25° 48′–26° 7′	25° 55′	26° 41′
$c \wedge n$, $0001 \wedge 2\bar{1}\bar{1}6$	6	33 54 –34 46	34 26	33 50
$c \wedge o$, $0001 \wedge 2\bar{1}\bar{1}4$	19	44 19 –46	45 3	45 9
$c \wedge r$, $0001 \wedge 6\bar{3}\bar{3}8$	3	55 46 –56 53	56 18	56 27
$c \wedge l$, $0001 \wedge 6\bar{3}\bar{3}7$	5	59 10 –60 33	59 50	59 53
$c \wedge p$, $0001 \wedge 2\bar{1}\bar{1}2$	22	63 12 –63 46	63 30	63 33½
$c \wedge x$, $0001 \wedge 6\bar{3}\bar{3}4$	6	71 17 –72 30	71 51	71 39
$c \wedge y$, $0001 \wedge 2\bar{1}\bar{1}1$	4	76 48 –75 36	76 13	76 2
$c \wedge z$, $0001 \wedge 6\bar{3}\bar{3}2$	7	79 17 –80 39	80 4	80 35

An examination of the above table will give an idea of the frequency of occurrence of the different pyramids and the accuracy of the determination.

All of the measurements which have not already been given in Tables I and II are collected together in the following table where they are again arranged into groups, which indicate the occurrence of vicinal faces agreeing nearly with simple forms.

TABLE III.

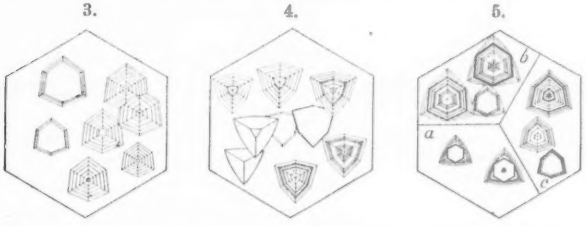
Mean angle on the base.	Limiting measurement.	No. of these observed.	Simple form to which they approximate.
23°		1	$2\bar{1}\bar{1}10$, $\frac{1}{5}$–2
35 44′	35° 30′–36°	6	*n*, $2\bar{1}\bar{1}6$, $\frac{1}{3}$–2
43 40	43 15 –44	5	*o*, $2\bar{1}\bar{1}4$, $\frac{1}{2}$–2
57 40	57 26 –57 53′	2	*r*, $6\bar{3}\bar{3}8$, $\frac{3}{4}$–2
61 37	60 47 –62 41	4	*p*, $2\bar{1}\bar{1}2$, 1–2
73 2	73 –73 5	2	*x*, $6\bar{3}\bar{3}4$, $\frac{3}{2}$–2
77 53	77 5 –78 53	4	*y*, $2\bar{1}\bar{1}1$, 2–2
88 15		1	*a*, $2\bar{1}\bar{1}0$, *i*–2

In all of the zones which were measured there was no indication of any hemihedral development of the pyramids.

Cleavage.—The cleavage of spangolite is very perfect parallel to the base; this was a great help in studying the crystals, as many of the measurements recorded in Tables II and III,

were obtained from cleavage-planes. Inclined to the base the crystals usually broke with a conchoidal fracture; in only one case a distinct cleavage was observed parallel to the pyramid p, the angle of the cleavage measured on to the base being 63° 28′, calculated 63° 33½′. Thin plates of the mineral are non-elastic and brittle.

Etching.—Experiments made by etching the mineral with acids gave results which add very much to a proper understanding of the crystals. It is readily soluble in dilute mineral acids and the perfect basal cleavage makes it easy to obtain orientated sections suitable for etching. The figures differed both with the character and strength of the acid, but always showed a decided hemihedral and rhombohedral symmetry. Fig. 3 represents the character of some etchings produced by dilute sulphuric acid. The figures which are very perfect are about ·066^{mm} in diameter and have the shape of a section across a scalenohedron. Some of the depressions are bounded below by a basal plane, others taper to a point while the scalenohedrons oscillate and give rise to delicate striations which are beautifully brought out under the microscope by a slight change of focus. The obtuse angle of the scalenohedron section measured under the microscope was about 133°, from which we calculate that its relation to the lateral axis is $a : \frac{5}{3}a : \frac{5}{2}a$, which requires an angle of 133° 10′. Fig. 4 represents some etchings produced by very dilute sulphuric acid: 1^{cc} of concentrated H_2SO_4 diluted with 80^{cc} of water. These also have a scalenohedral cross section and are about ·06^{mm} in diameter.



The obtuse angle of the cross sections measures about 152°, from which its relation on the lateral axes $a : \frac{4}{3}a : 4a$ can be calculated, which requires an angle of 152° 12′. There are also some steep rhombohedral depressions, with somewhat curved contours developed on this section. Some of the etchings produced by hydrochloric acid are shown in fig. 5, where the hexagon is divided into three parts. The figures shown in part a represent deep hexagonal depressions whose cross section is that of a pyramid of the second order, these have a diameter of about ·035^{mm} and are surrounded above with shal-

low and very delicate rhombohedral depressions with curved contours. In part *b* we have again scalenohedral, surrounded by shallow and more delicate rhombohedral, depressions. The obtuse angle of the scalenohedral sections measured 129°, from which its relation on the lateral axes $a:\frac{7}{4}a:\frac{7}{3}a$ can be calculated, which requires an angle of 129° 26′. In part *c* we have again represented simple scalenohedron depressions which are about ·025^{mm} in diameter and were produced by a very dilute acid, 1^{cc} concentrated HCl diluted with 160^{cc} of water. The obtuse angle of the scalenohedron measured about 142°, indicating a relation on the lateral axes of $a:\frac{3}{2}a:3a$, which requires an angle of 141° 48′. With nitric acid the figures are very similar to those produced by hydrochloric; in all cases it was observed that with very dilute acids there was a tendency to form scalenohedral and with stronger rhombohedral depressions. When we compare the position of these rhombohedral and scalenohedral etchings to the outer hexagon, which in figs. 3, 4 and 5 indicates the outline of the crystal section, we see at once that the pyramids on the mineral must be of the second order. It should be stated here that the etchings were of very great beauty and perfection, the outline of the scalenohedral cross sections being in almost all cases very distinct and free from distortions of any kind, so that the angles could be measured with comparative accuracy.

Optical properties.—The color of the mineral by reflected light is dark green, cleavage plates by transmitted light are light green. Prof. H. L. Wells examined a basal section of the mineral ·4^{mm} thick with the spectroscope. When the slit was very narrow the light transmitted by the mineral gave a narrow spectrum with a maximum of light in the green at about λ525. There was a total absorption of the red and yellow, running well into the yellowish-green. At the other end of the spectrum there was a decided absorption of the blue and a total absorption of the violet. Pleochroism is not very marked. The ordinary ray is green while the extraordinary is a decided bluish green. Cleavage plates show perfectly normal optical properties In convergent polarized light they yield a black cross surrounded by rings which are bordered by green and blue. The double refraction is quite strong and negative. Considerable difficulty was obtained in making a prism from a small crystal of the mineral with its edge at right angles to the perfect basal cleavage, but a small one was obtained, with an angle of 37° 48′, from which the indices of refraction were determined. The prism was opaque to the red and yellow lights of lithia and soda flames, even to the yellowish-green light of a thallium flame. With an ordinary kerosene flame the prism yielded two narrow green spectra with a minimum deviation

of 26° 25′ for the extraordinary and 28° 46′ for the ordinary, measuring from the brightest part of the spectra, which from the spectroscopic examination we have located at about λ 525, and we obtain for the two indices of refraction ω 1·694, ε 1·641.

Other physical properties.—The hardness of the mineral on the basal plane is about 2, on the pyramidal faces nearly 3. The specific gravity was taken very carefully with a chemical balance on the purest material, which was selected for chemical examination. After boiling the crystals in water, to expel any air, three separate portions weighing respectively 0·2143, 0·1787 and 0·1538 grams gave 3·147, 3·133 and 3·142, an average of 3·141 as the specific gravity.

Chemical composition.—More than three grams of exceptionally pure material were readily obtained by sacrificing about one-half of the crystals on the specimen. As the material was somewhat limited a method of analysis was adopted by which nothing could well escape detection and a qualitative and quantitative analysis was carried on with a single sample, the results of which are given below. The fourth analysis was made on an entirely different sample from that which yielded the figures in the first three columns.

	I.	II.	III.	IV.	Average.	Ratio.		Calculated for $Cu_6Al ClSO_{10}9H_2O$
SO_3	----	10·08	10·11	10·14	10 11	·126	1·01	10·03
Cl	4·12	----	4·10	4·11	4·11	·116	0·93	4·45
Al_2O_3	6·59	----	6·51	6·70	6·60	·064	0·51	6·45
CuO	59·57	....	59·47	59·50	59·51	·7495	6·00	59·75
H_2O	----	20·32	----	20·49	20·41	1·134	9·07	20·32
					100·74			101·00
		O, equivalent of Cl....			·92			1·00
					99·82			100·00

The analysis yields a ratio of $SO_3 : Cl : Al_2O_3 : CuO : H_2O$ = 1·01 : 0·93 : 0·51 : 6·0 : 9·07 or very nearly 1 : 1 : ·5 : 6 : 9, from which we obtain a rather complicated and remarkable formula, $Cu_6AlClSO_{10}, 9H_2O$. No doubt can however exist concerning this formula; not only was the material beautifully crystallized and of unusual purity, but the analysis of two separate samples are identical within the error of analysis and the ratio is throughout very sharp; moreover the calculated composition agrees very well with the results of analysis. A slight deficiency in chlorine may result from a partial replacement of that element by hydroxyl, which, if true, would diminish somewhat the slight excess of water. The method of analysis was as follows: A weighed quantity of the mineral lost water slowly by standing in a desiccator over sulphuric acid, amounting to 0·30 per cent in thirty-six hours, but it regained almost all of this loss

by standing uncovered in the air. Heated for an hour at 100° C. it lost about 0·49 per cent, but also regained this by standing in the air. The analyses were all made on air-dry powder. Water was determined by heating the mineral, weighed in a platinum boat, in a hard glass tube containing a loose plug of sodium carbonate at one end, through which the water vapors were conducted before absorption in a weighed chloride of calcium tube. A good deal of chloride of copper distilled off from the mineral. In some cases the contents of the boat was dissolved in nitric acid, the tube cleaned out carefully and a complete analysis made on one portion. A new portion being taken it was dissolved in nitric acid and the chlorine precipitated with silver nitrate. The weighed silver chloride when tested was found to contain no bromine or iodine and when ignited in hydrogen gas yielded a weight of metallic silver agreeing with the composition AgCl. After removing the excess of the silver from the solution with hydrochloric acid the SO_3 was precipitated with $BaCl_2$, care being taken to avoid a loss owing to the solubility of $BaSO_4$ in the aqua regia which was present in the analysis. After separating the excess of barium with sulphuric acid the solution was evaporated to expel the nitric acid after which the copper was precipitated with hydrogen sulphide and weighed after ignition in hydrogen gas as Cu_2S. A portion of the copper precipitate was carefully tested for other metals, but none were found. The filtrate from the copper sulphide, when evaporated to dryness and ignited left a residue which proved to be sulphate of alumina; this was dissolved in acid, precipitated in ammonia and weighed as Al_2O_3. A weighed quantity of the oxide was carefully tested for beryllium, but none was found, and after conversion into sulphate and evaporation with the right quantity of K_2SO_4 it yielded alum crystals. The filtrate from the alumina yielded no perceptible residue when evaporated to dryness proving that everything had been separated from the solution.

Pyrognostic and chemical tests.—Before the blowpipe the mineral fuses at about 3 to a black slaggy mass, coloring the flame green. On charcoal with soda in reducing flame it yields globules of metallic copper. Heated in the closed tube gives abundant water which has a strong acid reaction. Insoluble in water, but readily soluble in dilute acids.

There is at present no known mineral similar to spangolite in composition; the very rare connellite from Cornwall, England, whose chemical composition has never been determined, is the nearest approach to it, as it contains, according to Connel, copper in combination with sulphuric and hydrochloric acids, but the crystalline form and physical properties of the two minerals are entirely distinct. As far as can be found these two

minerals and sulphohalite, $3Na_2SO_4$, $2NaCl$; Caracolite Na_2SO_4, $Pb[OH]Cl$ and Kainite $MgSO_4$, KCl, $3H_2O$ are the only mineral occurrences of sulphate and chloride in combination. The occurrence of small quantities of alumina in a copper mineral, although not unknown, is certainly very unusual. It is also interesting to note that the alumina in the formula, one atom, is just sufficient to satisfy the quantivalence of the total acids $[AlCl]SO_4$, leaving six molecules of cupric oxide basic.

Before closing the author desires to express the hope that some one living in the neighborhood of Tombstone, Arizona, will take an interest in examining both the collections and ores of that region so as to secure, if possible, an abundant supply of this mineral.

Mineralogical Laboratory of the Sheffield Scientific School,
New Haven, March, 1890.

ART. XLVII.—*Archæan axes of Eastern North America;* by JAMES D. DANA.

IN my paper read before the Geological Society of America at its Toronto meeting in August last, and since published by the Society, after speaking of the Archæan range or series of ridges along the course of the Appalachian Chain from Canada through Vermont to Georgia as the Appalachian *protaxis*, I briefly mentioned the parallel ranges east of the protaxis in New England and Canada, and referred to the geological importance of the included troughs or basins. I return to the subject to make some additional explanations.

The Appalachian protaxis, the earliest line of heights in the history of the mountain chain, extends, with interruptions, after a long course between the New England boundary and the river St. Lawrence, through the eastern half of Vermont, eastern Berkshire, northwestern Connecticut, Putnam, Orange and Rockland counties in New York, northwestern New Jersey, South Mountain in eastern Pennsylvania, and thence southwestward through Virginia and beyond to South Carolina and Georgia—in all over 1250 miles. The parallel eastern ranges, having a general N.E.–S.W. trend, are continued into Newfoundland, range succeeding range quite to the farthest extremity of this great continental promontory. These ranges, it should be understood, like that of the protaxis, are not simple continuous lines, but broken lines, with often parallel subdivisions, they having the composite style of all mountain ranges.

Why there should be so large an Archæan-ribbed projection of the continent north of the parallel of 42°, and little corresponding to it farther south awaits explanation. It may be connected with the fact that the continental margin north of 42° is backed so closely by the eastern arm of the V-shaped Archæan nucleus, which is here made up of the Adirondacks and the hills just north of the St. Lawrence. And the *landward* bend of the protaxis and Alleganies south of lat. 42° N. (to a west-southwest course) across central Pennsylvania (and paralleled in the coast-line) may have the reverse cause.* The trough between the Adirondacks-and-Canada Archæan and the protaxis—the St. Lawrence-Champlain trough—is not fifty miles in mean width. This trough was an open channel to the Interior Continental sea receiving thick rock deposits until the close of the Lower Silurian; but at this epoch the Lake Champlain portion ceased rock-making cotemporaneously with the formation of the Taconic Mountains and the general uplift of the Green Mountain area along the western New England border, not to resume it again except temporarily.

The Ranges.—The ranges, partly or wholly Archæan, lying to the east of the Protaxial Range are the following—numbering the protaxis I, as it is the first in the series:

II The NEW HAMPSHIRE RANGE: extending from the borders of Maine and Canada through New Hampshire and Massachusetts into Connecticut, making the east side of the Connecticut Valley.

III. The MOUNT DESERT RANGE: commencing near Chaleur Bay, on the Gulf of St. Lawrence, and continued southwestward through New Brunswick to the coast of Maine, where it includes the Mt. Desert region, and thence into eastern Massachusetts between Boston and Worcester, and probably into Connecticut.

IV. The ACADIAN RANGE: commencing in the western part of northern Newfoundland, east of White Bay and extending thence to St. George Bay and Cape Ray in southwestern, and beyond over eastern Nova Scotia; and thence, probably, beneath the sea along the course of shallow soundings, as sustained by Professor W. O. Crosby, to Plymouth and Cape Cod in eastern Massachusetts.

The Archæan ridge of the long northwestern arm of Newfoundland, north of the Bay of Islands, making the northern part of the so-called "Long Range," is a more western range than the preceding; it is separated from the Archæan region of Labrador by the Belleile strait or channel.

* The landward bend of the Rocky Mountain protaxis (Archæan) in Montana and Idaho (to the east-southeast) between the parallels of 42° and 45° may have a like origin—the bend *like that on the Atlantic side*, being opposite the southern extremity of the nucleal V.

V. The CENTRAL-NEWFOUNDLAND RANGE: extending over a broad region east of the Exploits River Valley, to the east side of Exploits Bay.

Besides these ranges there appear to be two other more or less complete ranges separating pairs of bays that head together, and then, the easternmost, that of Ferryland.

The Troughs.—The troughs into which the country is topographically divided by these ranges were the rock-making troughs or basins of Paleozoic time, and partly of Mesozoic, and were more or less independent in their geological history, especially after the Lower Silurian era. The Lower Silurian and Cambrian beds often spread from one of these troughs to another, and across the protaxis, over portions that were then submerged. But the mountain-making disturbances at the close of the Lower Silurian ended in giving greater height and breadth, and Siluro-Cambrian annexations, to the Archæan, not only in the Green Mountain region, but also, as evidence from unconformabilities proves, in the Mt. Desert and Acadian ranges; and probably in others.

The troughs or areas between the ranges above enumerated, are the following.

A. Between Ranges I and II, The CONNECTICUT VALLEY TROUGH: containing, Lower Silurian, Upper Silurian and Devonian beds in the state of metamorphic schists (mica, hornblendic, chloritic) and crystalline limestones, but nevertheless affording fossils of each of the eras for their identification; and containing also, the Connecticut Valley Sandstone or Jura-Trias beds, which are uncrystalline and fossiliferous.

B. Between Ranges II and III, the GASPÉ-WORCESTER TROUGH: extending from Gaspé, on the Bay of St. Lawrence, over much of northern New Brunswick and central Maine, and continued to Worcester, Mass. and possibly beyond; and containing Cambrian? Lower Silurian, Upper Silurian, Devonian and Carboniferous beds. The rocks are unaltered at Gaspé, but become more or less metamorphic in southwestern Maine and graphitic slates and mica schists of Carboniferous age at Worcester, these last being identified by fossil plants.

C. Between Ranges III and IV, the ACADIAN TROUGH: beginning in northern Newfoundland west of the northern part of Long Range and extending to St. George Bay and Cape Ray, in southwestern; passing thence over the region of the Magdalen Islands, in the Bay of St. Lawrence to Nova Scotia and New Brunswick on either side of the Bay of Fundy; and thence to the region of Boston and Massachusetts Bay, and to that of Narragansett Bay in Rhode Island; and including rocks from the Cambrian to the Jura-Trias as identified by fossils. The rocks are metamorphic to the south. Strata from

the Cambrian to the Carboniferous are identified by fossils for 300 miles in Newfoundland* (the Carboniferous through the southern half of the 300 miles), and also, for the western margin of the trough, in New Brunswick–Maine and in Massachusetts–Rhode Island; the outcrops of Lower Silurian to Devonian extending along the coast region of Maine for fifty miles or more, or at least to Narraguagas Bay in Millbridge.†

The length of the Acadian trough between the limits stated is about 1000 miles, and between the most northern and southern localities of coal over 800 miles. It was probably therefore, a great feature in the Carboniferous history of Paleozoic North America; and it is a relatively small one in existing coal areas only because of the vast amount of erosion which has since taken place—a large part of it, probably, after the epoch of disturbance at the close of Paleozoic time.

The continuation of the Coal-measures and associated rocks from southern Newfoundland in a line toward White Bay proves that the Acadian trough extends by the east side of the northern section of "Long Range," and that the country on the west side is not its proper continuation. The latter becomes to the north the Belleile Straits or trough, and in it the rocks are Lower Silurian and older, like those of the lower part of the St. Lawrence trough.

D. Between Ranges IV and V, The Exploits River Trough, extending along Exploits River across Newfoundland, southwestward, to La Poile Bay and White Bear River, the length 200 miles, containing rocks reported by the Canadian Survey to the Upper Silurian.

There may be, also, the partially independent (E) Trinity—Placentia and (F) Conception—St. Mary troughs, the borders of which have afforded Cambrian fossils; and perhaps a subordinate Fortune Bay trough.

In view of the great extent of the Newfoundland Banks, and the possibilities attributable to erosion, our knowledge is very uncertain as to the loss in size and in fossiliferous strata which may have taken place in eastern Newfoundland. The shallow water area to the southeast, out to the 100-fathom line, is much larger than all Newfoundland, and the distance is 250 miles to the 50-fathom line, the outline of the Banks proper.

* Murray mentions in his Report of 1866, the discovery of *Olenellus Vermontanus* on the west coast at the entrance to Long Arm, of Canada Bay, (about latitude 50° 45′), with Devonian beds (containing *Psilophyton, Lepidodendron Chemungense*, etc., as identified by Dawson) just north, at Cape Rouge Harbor. The localities are near the west margin of the trough, the only part there extant. Mr. Murray, formerly of the Geological Survey of Canada, is the chief source of our knowledge of Newfoundland geology.

† C. H. Hitchcock, Agric. and Geol. of Maine, 1861, 1863; and on the vicinity of Cobscook Bay, N. S. Shaler, Am. J. Sci., xxxii, 35, 1886.

The troughs are areas, for the most part, of independent geological work.—It is of great geological interest that subsequent to the Lower Silurian era, if not also before, these troughs were, for the most part if not wholly, areas of independent geological work, and that in them all the geological formations of this part of North America, up to and including the Jura-Trias, were made. This is apparent from the facts respecting the rocks and fossils of the troughs already mentioned.

The thickness of the Silurian and Devonian rocks of the Connecticut Valley trough is not known; but it is certain that the Jura-Trias rocks of the southern half of the valley have a thickness of at least 5000 feet; and this proves that subsidence to this large amount took place in the valley at so late a date in geological history.

The Acadian trough has its thick Silurian and Devonian formations yet unmeasured; and then, some 16,000 feet of Carboniferous rocks, and later, a great thickness of Jura-Trias—as great probably as in the Connecticut valley; moreover the Newfoundland part of the trough has, according to estimates made, some 6000 feet of Carboniferous beds near St. George Bay. 20,000 feet of subsidence is thus recorded for parts of the Acadian trough after the Devonian era. And probably as much took place before the Carboniferous era.

The other troughs bear evidence of like subsidence and work; but we have no definite estimates as to the thickness of the deposits.

Further, we find that the Connecticut valley trough was in its southern half, through a long period, that of the Jura-Trias, a fresh or brackish water trough. Again, the Gaspé-Worcester trough became a trough of fresh-water marshes in its southern part during the Carboniferous era. The Acadian trough, passed from a salt-water channel to a condition of great fresh-water marshes and estuaries after the Carboniferous period had set in; and this may possibly have been its condition for a length of 800 miles. It was while in this state that the trough in part of Nova Scotia sunk 13,000 out of the 16,000 feet. And after the Carboniferous era of fresh-water marshes, alternating with fresh or brackish water estuary conditions, during deep subsidence, had passed, and after also the mountain-making events which closed Paleozoic time in Nova Scotia as well as the Continental Interior, the trough still existed and in some parts continued its work through another long period of deep deposition and subsidence,—that of the Jura-Trias.*

* The broad margin of the continent south of New York had its troughs in the Jura-Trias. But each of the troughs contains Jura-Trias rocks alone; the beds rest on the crystalline Archæan, or on Lower Silurian rocks crystalline or unerys-

In each case it appears that geological work went forward as long as subsidence was continued; and that stoppage of subsidence was stoppage of work, in accordance with a general geological law. Some would put it—Stoppage of work of deposition was genetically stoppage of subsidence; but the question is not yet so settled. Moreover, the deposits in each trough were thickest along some axial line in the trough, or more than one, where its subsidence was greatest.

The facts illustrate strikingly the great truth that the earth's features even to many minor details were defined in Archæan time, and consequently that Archæan conditions exercised a special and even detailed control over future continental growth. The extension of North America to the most eastern point of Newfoundland, and beyond it, was determined in this beginning time; and likewise, that of the European Continent to the Hebrides, in front of the Scandinavian Archæan area.

ART. XLVIII.—*On the Metamorphic Strata of Southeastern New York;* by FREDERICK J. H. MERRILL.

OF the strata comprised in the metamorphic terrane of southeastern New York there are two principal divisions.

First, in Rockland, Orange, Putnam and Dutchess counties, the granitoid gneisses and granulites of the Highlands, which, with their continuation in New Jersey, can be shown stratigraphically to be pre-Cambrian, since they underlie unconformably in southern Dutchess County, N. Y., and at several points in New Jersey, a basal Paleozoic quartzite of Potsdam or Lower Cambrian age.

Secondly, in Westchester and New York Counties the gneissoid quartzites and arkoses overlain by crystalline limestones and mica schists, which border the rocks of the first division on the southeast and have been regarded as altered Paleozoic rocks of Ordovician or Cambrian age by Professors W. W. Mather and J. D. Dana.

The metamorphic rocks of the New Jersey Highlands were first definitely classified by Dr. N. L. Britton as a result of his studies in 1885 and 1886.* In this terrane he identified three groups: first; a Massive Group, devoid of bedding planes,

talline. The facts are of interest here; for the troughs are all parallel to the courses of the Appalachian Mountains, curving with all their long curves; and at the same time, as is true also for the Nova Scotia and Connecticut valley areas, the deep subsidence went forward in each—2000 to 5000 feet—without giving access to salt-water. The troughs were kept filled with sediments.

* Annual Report Geol. Survey of New Jersey, 1885–1886.

described by him as being the oldest formation exposed in that state, and almost entirely composed of "hornblendic granite": second, an Iron-bearing Group, resting conformably on the preceding, well stratified, and comprising bedded granulites and magnetite deposits, above the latter being crystalline limestones containing magnesian silicates in various stages of alteration: third and uppermost, a "Schistose Group," composed of micaceous gneisses, of mica schists sometimes containing graphite, and hornblendic and pyroxenic schists of varied composition. The basal Paleozoic quartzite has not yet been found to rest on strata of the third group, and the relative age of the latter remains in doubt.

In the study of the metamorphic rocks of the New Jersey Highlands and in a preliminary examination of the Hudson River section, the writer was associated with Dr. Britton and has since made a more extended study of the latter. The facts there observed corroborate the general results of Dr. Britton's stratigraphical work in New Jersey.

The basal member of the pre-Cambrian terrane of southeastern New York and New Jersey, is a granitoid hornblende-gneiss consisting chiefly of quartz, orthoclase, plagioclase and hornblende. Magnetite and zircon sometimes occur as accessories. As stated by Dr. Britton the rock is devoid of bedding planes and has only a parallel arrangement of its minerals to denote macroscopically its sedimentary origin. Its microscopic structure, however, also suggests its detrital and metamorphic character.

This rock is not a granite although usually called by that name. In addition to the parallel arrangement of its minerals which would differentiate it from the normal granites, its structure shows that it never attained that condition of molecular freedom which would be necessary to enable its mineral components to assume a crystalline form. The quartzes and feldspars occur in irregular masses interlocking at their margins and in no case show crystalline boundaries. The hornblende, which is *allotriomorphic* and fills the irregular interstices between the other mineral particles, has probably been developed in the process of metamorphism from aluminous mud containing iron, lime and magnesia. As in rocks which have been developed from the plastic or fluid state the magnesia-iron silicates according to Rosenbusch, are *idiomorphic* with respect to the feldspars and the latter are idiomorphic with respect to the quartzes, the structure of the rock in question seems to demonstrate that its component minerals are not developed from a magma but are merely the fragmental particles of a sedimentary rock and that during metamorphism only a slight degree of molecular freedom was attained by them.

The thickness of the basal member is at present indeterminate, as nothing has been found beneath it, and in the Hudson River section it is seen to descend below tide-level. The maximum thickness exposed is in Breakneck Mountain, of which the summit is said to be 1787 feet above tide. Whatever be the true height of the mountain, its central mass from tide-level to the summit consists of hornblende-gneiss, and whether it be anticlinal or monoclinal in structure, an equivalent thickness of this rock is exposed.

The second member or Iron-bearing Group, as Dr. Britton has stated, consists essentially of granulites, this name being used by him and the present writer to describe subcrystalline, well stratified metamorphic rocks composed principally of detrital quartz and feldspar. They are highly metamorphosed arkoses, and differ essentially from the under-lying formation in the absence of magnesia-iron silicates such as hornblende and biotite. The comparative absence of silicate minerals containing iron is indeed the conspicuous feature of this member taken as a whole. In some places, as at Garrisons, a pale yellowish mica is present, giving the rock the semblance of a granite, under which name it is quarried, and in close proximity to some of the magnetite beds in New Jersey, biotite and hornblende are quite abundant. This formation is at least 500 feet thick.

The beds of magnetite appear to occur at various levels in the second group and offer little evidence of their origin. If, however, it were known that the rock which furnished the detritus out of which these granulites were formed, contained magnetite distributed through it in any appreciable quantity there would be good reason for the conclusion that the magnetite beds of this horizon originated as beds of magnetic sand concentrated by wave action. There is no indication that they originated as bog ores. They are simply lenticular beds enclosed by a stratified metamorphic rock formed of quartz and feldspar sand and there is no adjoining rock of which the composition would suggest that it is a metamorphosed soil. There is, besides, no indication of a former land surface on which these beds might have been formed. The only suggestion of organic agency is in the apatite which occurs with the iron ores at some of the mines and this, if it were organic, could have been derived from marine organisms as well as from terrestrial. It is not, however, by any means certain that this apatite is organic, since the mineral is a frequent accessory in various eruptive rocks.

The strata of Dr. Britton's schistose group and the limestones which, according to him, occur near the top of the second member are found near the Hudson River, in Orange County at Fort Montgomery, and in Putnam County between

Highlands and Garrisons. It has not yet been determined whether they should be regarded as part of the system to which the two lowest groups or members belong, nor have their relations been determined with respect to the Manhattan Group (hereafter defined). As before stated, no Ordovician or Cambrian Rocks have been found to rest upon them and hence their pre-Cambrian age cannot, as yet, be predicated with certainty.

The thickness of the pre-Cambrian rocks in the Hudson River Valley may, therefore, be stated as between 2300 and 2800 feet. As to their age, it is difficult to predicate anything on account of their isolated position. The "upper member," or granulitic group may or may not be the equivalent of the Huronian. There is nothing but its unconformable position immediately below the Cambrian quartzite to suggest such equivalence, and as it seems to be conformable to the "basal member" that would have to be included in the same horizon.

The magnetite beds of this region have been compared by Dr. Britton to those of the Grenville series in Canada, and they may be equivalent but until the Laurentian of Eastern Canada has been studied and classified with the aid of modern methods of research any attempt at correlation will be unsatisfactory.

The stratigraphy of the Highland region as displayed in the section along the Hudson River is very simple. A small number of anticlinal ridges, 900 to 1700 feet in height, with a northeasterly trend, are intersected by the Hudson River valley. Along the lines of these the basal member of the Archæan is exposed and resting on their flanks and in the synclinal troughs the rocks of the Iron-bearing Group appear.

The most northern axis is that of the Fishkill range which is probably a continuation of the Wawayanda Mountain axis of Northern New Jersey, along which line in Orange Co. N. Y. occur a number of isolated hills of gneissic rock known as Sugar Loaf Mountain, Goose-Pond Mountain, Peddler Hill, Rainer Hill, Mosquito Hill, Round Hill and Woodcock Hill.

Second is that of Storm King and Breakneck Mountains, closely related orographically to the axis of Crow Nest Mountain and Bull Hill or, as the latter is sometimes called, Mt. Taurus. There is probably a fault line between these two axes and nearly parallel to them, but the structural details have not been accurately determined. A fourth axis is that which crosses the Hudson at West Point. A group of axes crosses the Hudson along the lines of Fort Hill, Sugar Loaf Mountain, Anthony's Nose and Bear Hill and finally the anticlinal of Manitou Mountain and the Dunderberg closes the succession. These folds generally pitch steeply to the S.W. In this re-

spect the most noticeable are those of Anthony's Nose and Sugar Loaf, the latter of which exhibits this peculiarity by its profile to the most careless observer.

On the southeastern flank of Dunderberg and Manitou Mountains the stratified granulites again appear and these are succeeded after a drift-covered interval near Peekskill and Jones Pt. by slightly metamorphosed sandstones, limestones and slate, presumably of Paleozoic age, the relation of which to the sub-crystalline rocks of Westchester and New York Counties is still an interesting problem.

Younger Rocks.—The metamorphic strata of New York and Westchester Counties have long attracted the attention of geologists and several attempts have been made to solve the problems of their age and history. The extended researches of Prof. Jas. D. Dana on the relations of the limestone belts in the vicinity of Manhattan Island have furnished a clue to the stratigraphy, and, after a careful study of a portion of the terrane to which those limestones belong, the writer is enabled to announce the following general results. As Prof. Dana has noted (Am. Jour. Sci., III, vol. xxi, p. 439), the beds underlying the limestones of New York County are highly quartzose, while those overlying them are chiefly micaceous. Throughout Westchester County south of the latitude of Sing Sing, an area of about one hundred square miles, the writer has found this lithological difference to prevail. The exact relation of the lower beds to the granitoid gneisses and granulites of the Highlands of Rockland, Orange and Putnam Counties has not yet been determined by the writer, but his investigations have satisfied him that the former, with the exception of the limestones, are distinctly detrital rocks in which are preserved the fragmental character of the quartz and feldspar which they contain. The mica, chiefly biotite, is of metamorphic origin, having been developed from aluminous mud rich in potash, iron and magnesia.

As the limestones of the region under consideration contain no organic traces, so far as we know, there is no direct clue to their origin, but in the absence of evidence to the contrary we may believe that the carbonate of lime was separated by organic agencies from the sea water which held it in solution. The well known chemical theory of Dr. Hunt accounts very satisfactorily for the presence of bicarbonate of lime in sea water, but it does not account so well for the separation of the carbonate from solution, and as this separation is effected very extensively at the present time by various marine organisms and as the cases of chemical separation of carbonate of lime from solution in sea water are very few, we are justified in believing that the former process was in operation as far back in

the earth's history as the sea water was inhabited by creatures possessing skeletons of carbonate of lime. The source of the magnesia so abundant in the limestone is yet undetermined.

The lowest stratum yet recognized among the Westchester County rocks is a reddish gneiss which forms the central mass of some of the hills in Yonkers where it is well exposed, and consists of small grains of detrital quartz with fragments of reddish orthoclase and a few crystals of biotite which have developed during the process of metamorphism. From its macroscopical characters the rock would be called a gneiss. From its microscopic structure it would be called a metamorphosed sandstone or arkose. As the name quartzite gneiss has been applied in Germany to rocks of analogous structure, it is proposed to designate the rock in question as an *arkose gneiss*. It may be objected that all gneisses were quartzites or arkoses previous to their metamorphism, but there is an evident necessity for the use of some descriptive term which will convey the idea of comparatively unaltered detrital structure and differentiate such a rock as this from the pre-Cambrian granitoid gneisses of Putnam County.

The thickness of the red gneiss referred to has not been determined, as no section has been found which shows its relations to the formation beneath it, but it is believed to rest upon the stratified granulites which form the second or upper member of the pre-Cambrian formation. Since the best exposures of the red gneiss have been found within the limits of Yonkers and its relations to the overlying stratum are well shown within the limits of that city, it is proposed to call it the *Yonkers gneiss*. Outcrops of this rock are frequent along the shores of the Hudson and good exposures may be found at Hastings, on the property of Dr. Draper; on the river near the southern border of Tarrytown; between Scarborough and Sing Sing stations near the railroad; along the southeast shore of the mouth of Croton Bay on the property of Orlando B. Potter, Esq.; and a little south of Oscawana Station, on Oscawana Island; it also probably occurs in the ridge which separates Annsville Cove from the valley of Peekskill village. The best exposures are in Yonkers, on and near Jerome avenue, a little north of the New York City line.

With regard to the variations in the composition and structure of the Yonkers gneiss, the most important are an increase in the proportion and size of the feldspar fragments in approaching the Laurentian Highlands.

Overlying the reddish Yonkers gneiss and beneath the crystalline limestone is a stratum of thinly bedded gray quartzite gneiss. This contains but little feldspar and its component beds vary in composition from almost pure quartz to a mixture

of quartz and biotite or hornblende. Occasionally, layers of pure biotite schist, an inch or two in thickness, are intercalated with white, coarsely granular quartzite. This rock forms the summit and eastern slope of the ridge which separates the Sawmill River valley from that of the Hudson and also occurs in that on the east side of the Hudson between Yonkers and Spuyten Duyvil. It forms, as well, the anticlinal ridge of Fordham Heights which borders the east shore of the Harlem River and of which the southern extremity forms the long narrow hill by the northern end of Seventh avenue and which separates the latter from the Boulevard.

In general terms this quartzite gneiss is the gray rock used for a building stone in southern Westchester County. The Yonkers gneiss is also used for building, but not so extensively and is characterized by its reddish color. No section has yet been found which shows accurately the thickness of this gray gneiss. It is at least two hundred feet thick and, in many exposures, has an aggregate thickness of half a mile, but in these it is apparently repeated many times by folding. As in most cases the folds are isoclinal and their arches have been removed by erosion, there is little stratigraphical evidence of the thickness of the stratum thus folded.

Since this rock is well exposed and its stratigraphical relations are well shown in the Fordham Heights it is proposed to call it the *Fordham gneiss.*

The Fordham gneiss varies widely from the normal type, in places, through the presence of hornblende and garnet and an increase in the amount of feldspar and mica, but the localities of variation are comparatively few.

Between the Fordham gneiss and the crystalline limestone of the Hastings Quarry and in Yonkers at the south end of the railroad trestle near the Lowerre Race Track, a stratum of thinly bedded quartzite from five to ten feet thick is found. It seems probable that this is of wide distribution but on account of its slight thickness it is very rarely preserved when the limestone which rested upon it has been removed by erosion.

At Tuckahoe this quartzose stratum next beneath the limestone contains numerous flakes of biotite.

The position and stratigraphy of the limestone areas of Westchester County have been carefully studied by Professor Dana. My only contribution to the geology of these beds has been to determine the relations and character of the associated rocks, to note a few unrecorded outcrops and in a few cases to extend the limits of those previously known.

Professor Dana has estimated the thickness of the bed occurring in Tremont and the Harlem River valley at from six

hundred to seven hundred and fifty feet. The measurements of the writer would indicate that the thickness varies from six hundred to eight hundred feet, it being apparently greater on New York Island than in Morrisania. The eastern bed at Tuckahoe is but one hundred and fifty feet thick. For this rock I propose the name of *Inwood limestone*, from the locality on New York Island in the vicinity of which it is well exposed.

The rocks which overlie the limestone are highly schistose and consist largely of mica with a small proportion of quartz and usually little or no feldspar. Garnet, staurolite, fibrolite and cyanite are the chief accessories. There are some beds of gneiss among them, but these are very small and the studies of the writer enable him to state positively that mica preponderates in the rocks above the limestone beds. No sections have yet been found which would warrant an expression of opinion as to the *exact* thickness of these schists, but it probably exceeds one thousand feet.

The mica schist formation which belongs above the limestone is of very limited extent in Westchester County. A synclinal ridge of this rock extends from Park Hill, in Yonkers, northward along the east bank of the Saw Mill River and has been traced to Elmsford.

North of Croton landing the mica schist containing garnet and staurolite extends along the bank of the Hudson for about a mile and east to the norite area of the Cortlandt Series. Near Crugers the schists have been described by Professor Dana

Between the Bronx River and Long Island Sound, in Southern Westchester County, there is a considerable extent of mica schist but its limits are not determined. In Eastchester village, on the west shore of Eastchester Creek the rock is a gneissoid quartzite. At New Rochelle the rock along the shore of the Sound probably belongs below the limestone. The same rock, essentially a gneissoid quartzite, occurs on the shore of Mamaroneck Harbor, while Milton Point in Rye township seems to be composed of the mica schists. On the Hudson River shore, in general, the limestone areas are succeeded to the north by mica schists and to the south by the arkose gneisses.

As these uppermost beds are well exposed on Manhattan Island of which they constitute the principal rock formation they may well be called the *Manhattan schists.*

The name Manhattan Group was proposed in 1868 by R. P. Stevens, Esq., to include the rocks of New York Island and it seems proper that it should, for the present, be retained, including in it, with the Manhattan schists, the Inwood limestone and the Fordham gneiss, the Yonkers gneiss which though not

found on Manhattan Island, is evidently a part of the same littoral deposit to which the Fordham gneiss belongs. The Manhattan schists are the only beds now to be found on New York Island with the exception of the limestone areas described and mapped by Professor Dana and the small area of Fordham gneiss at the north end of Seventh avenue.

If in time this group be correlated with some other which has been previously described, the names here suggested may be unnecessary, but until the question is indisputably settled they are of use in referring to the formation and its subdivisions.

Intercalated with the Manhattan schists and also with the beds of the Fordham gneiss we find at a great number of localities, hornblendic and augitic strata of limited thickness, usually only a few feet. In composition these rocks resemble diorites and diabases, and in structure they are granular, but their present well stratified condition renders it difficult to say whether they are originally eruptive rocks or not. Whatever their origin they are now metamorphic rocks and as such may be called amphibolites and pyroxenites according to the terminology of Kalkowsky. It is probable that to rocks of this character we are indebted for some of our serpentines, notably that of 60th street near 10th avenue, New York City, for as originally suggested by Dana and lately demonstrated by Gratacap it is derived from the alteration of amphibole, and on 61st street near 11th avenue, a bed of amphibolite occurs, of which the line of strike passes through the well known and interesting serpentine above mentioned and which lies about 250 feet southeast.

Age of the Manhattan Group.—It is not yet in the power of the writer to contribute any positive information on this important question He has not yet found any decisive evidence of the age of the rocks in question. All the suggestive evidence, however, favors the view taken by Professor W. W. Mather and subsequently elaborated by Professor J. D. Dana, viz: that the rocks of the Manhattan Group are the metamorphosed equivalents of the Paleozoic beds of Southern Dutchess County.

After a careful study of the stratigraphy in the vicinity of Peekskill which seems to be the index of this geological chapter, and at other points along the northern margin of the Manhattan terrane, the writer concludes that if this group is pre-Cambrian, its identity as such has been obscured by a series of stratigraphic vicissitudes so complicated that it is beyond his powers, at present, to conceive them.

A fact which may be of much significance, is that, the Potsdam or Lower Cambrian sandstone of Southern Dutchess County lies unconformably on the second or granulitic member of the pre-Cambrian formation, and it is upon the same second member that the basal beds of the Manhattan Group rest. No unconformability has yet been found between the Manhattan Group and the underlying pre-Cambrian beds, and it is chiefly this lack of positive evidence that leaves the writer in doubt as to the geological equivalence of the former. Of equal significance, however, is the lack of unconformability between the Lower Silurian strata of Peekskill Hollow, Tompkins Cove, and Verplank's Point, which are but partially metamorphosed, and the metamorphic beds of the Manhattan Group which adjoins them.

The crystalline limestones of the Manhattan Group are, as already stated, highly magnesian and in this respect they correspond in composition to the Calciferous limestones of New Jersey which according to Professor Geo. H. Cook (Geology of New Jersey 1868) contain from seventeen to twenty per cent of magnesia.

In this abstract it has not been possible to give in detail the evidence upon which the writer's conclusions are based. A complete discussion of the evidence must therefore be reserved for future publication.

Art. XLIX.—*The Radiant Energy of the Standard Candle; Mass of Meteors;* by C. C. Hutchins.

The following investigation was undertaken with the primary object of finding, if possible, more trustworthy data for determining the mass of shooting stars; but a reliable determination of the radiation of the standard candle cannot fail to be of value for other purposes.

The apparatus employed in making the measurements was my thermograph,* the constant of which was found in the two following ways.

First method.—A copper Leslie cube, holding about 3 kilos. of water, was placed behind an opening of 16 sq. cm. in a wooden screen, which opening was closed by a movable shutter, by opening which the thermograph, one meter distant, could be exposed to the radiation from the cube.

The following quantities were then determined: dimensions of cube; weight of water contained in cube; water equivalent of cube; mean of the galvanometer deflections taken dur-

* Proc. American Academy, 1889.

ing the interval that the cube and its contents were falling 5° from a temperature about 65° above that of the air; time in seconds occupied by the cube in falling the 5° as above.

Knowing these quantities we can evidently compute in ergs per second the radiant energy passing through the sq. cm. of surface containing the thermal junction, and such that it will produce a deflection of one division of the galvanometer scale. A number of trials showed that 16·9 ergs per second was the quantity required.

Second method.—The constant was found by passing the rays of the sun through openings of 0·394 and 0·23 cm. diameter and observing the galvanometer deflections when the thermograph was exposed in the divergent beam at a point where the diameter of the beam was 4·2 cm. and then computing the deflection for the undiminished sunlight. Simultaneously with the above measures the radiation of the sun was observed with Pouillet's pyrheliometer.

The mean of several sets of measures by this method gave the constant 17·02; agreeing better than could have been expected with the results of the first method. The candle employed was the ordinary sperm candle, six to the pound. It burned in still air, without snuffing, 7·37 gm. per hour. The radiation of the candle was measured by placing it behind the screen in place of the cube employed in finding the instrumental constant, the exposures being made in the same manner as for the cube. The deflection given varied very much with the length of the wick of the candle, constantly increasing for a half hour or more after lighting. It therefore was necessary to observe the deflection at what was considered to be an average condition of the candle flame, that is, about 15 minutes after lighting, when a deflection of 75 scale divisions was obtained.

This number multiplied by the constant previously found gives the radiant energy which from the candle passes through each sq. cm. of a surface everywhere one meter from the candle, provided we assume that the candle radiates equally in every direction. To find the total radiant energy, we must, as a first step, know the area of cross section of the candle flame in a plane perpendicular to the direction of the flame to the opening of the thermograph. To learn this, an image of the flame was projected upon 400 sq. cm. of paper, taking care to have the projecting lens midway between the candle and paper. It was then easy to trace about the image of the flame with a pen, and this having been done ten times upon the same sheet, the whole sheet was weighed and then the tracings cut from it and also weighed. In this manner the section of the candle-flame was found equal to 1·303 sq. cm.

We now have the whole radiant energy of the candle—

$$\varepsilon = \frac{4\pi \times 100^2 \times 75 \times 17}{1{\cdot}303} = 1{\cdot}23 \times 10^6 \text{ ergs per second.}$$

To find what portion of this total energy lies in the visible spectrum could be satisfactorily accomplished only by measures made in every part of the spectrum of the candle. Such measures have been made by Langley* in the spectrum of an argand gas-lamp with a glass chimney. He finds 2·4 per cent of the total radiant energy to be visible. It is easy to compare the candle with such a lamp. At a certain distance from the thermograph an argand lamp, whose light was that of ten candles, gave a deflection of 238 scale divisions. When the lamp was replaced by the candle the deflection was 29. Hence we see that very nearly 2 per cent of the radiant energy of the candle is visible; or the visible part is $2{\cdot}46 \times 10^6$ ergs per second; about 10·9 ft. lbs. per minute.

We may now proceed to find the mass of a meteor, first upon the supposition that its rays have the same ratio of visible to total energy as do those of the candle, and later, correct, if possible, the value thus found.

Let the meteor at a distance of 50 miles have a light equal to that of Vega; let it continue for 2 seconds with a velocity of 25 miles per second. From the best data we find that if the meteor were at 1 meter distance the log of its candle power would be 3·9851. Hence to find the energy ε, we have:

log candle power	3·9851
log energy of candle	8·0899
log 2	0·3010
log ε	12·3760

We have for the mass, $m = \frac{2\varepsilon}{v^2}$, and employing the data assumed above we find $m = 0{\cdot}2936$ gm.

If the meteor in burning produce, for a given expenditure of energy, more light than does the candle, then a less mass than the one found would serve to produce the light given by the meteor. From what has been observed of the spectra of meteors, it is safe to conclude that their light is mainly due to incandescent vapors of the materials composing the meteors. It is also known that the spectra of these substances remain unchanged throughout very considerable changes of temperature, and we may therefore be permitted to draw conclusions from laboratory experiments upon these substances in the state of vapor.

* Science, vol. i, p. 482.

A lump of the Emmett Co., Iowa, iron meteorite was placed upon the lower carbon of an arc lamp and vaporized by the passage of the current. The light given by the meteor vapor was found, on the average, equal to that of 40 candles. The galvanometer deflection by the meteor at a certain distance from the thermograph was 223·2 scale divisions. At the same distance the candle gave a deflection of 55·4 divisions. From this we see that for a given expenditure of energy the arc of meteor vapor gives 10 times the light of the candle. Dividing the value of m obtained above by 10, we have $m = 0{\cdot}029$ gm. for the mass of a meteor giving the light of a star of the first magnitude, moving with nearly the parabolic velocity and lasting for 2 seconds.

Bowdoin College, March 12, 1890.

Art. L.—*Meteoric Iron from North Carolina;* by L. G. Eakins.

The iron here described was found in the latter part of 1880 on a farm near Ellenboro', Rutherford Co., N. C., and its nature remained unknown until February, 1890, when it was brought for examination to Mr. Stuart W. Cramer of the U. S. Assay office at Charlotte, N. C., who ascertained that it was a meteorite and secured half of the mass. This portion was sent by Mr. Cramer to the U. S. National Museum for description, and the iron was cut and divided between the Museum collection and that of the Assay office.

The weight of the original mass, as near as can be determined, was about 2,200 grams; in shape it was roughly two globular ends with a connecting bar, the total length being about 150^{mm}, with end diameters of 75^{mm}, and 50^{mm} in the middle.

The iron is very tough and highly crystalline, the Widmanstätten figure showing distinctly on a polished, unetched face, and after etching they are unusually strong. Small, irregularly distributed patches of troilite are visible and schreibersite also seems to be present. On account of the small amount of material that could be secured for analysis no attempt was made to determine carbon, and the sulphur found shows that very little troilite happened to be included in the material analyzed, which, of course, in such highly crystalline material could not represent the actual average composition without cutting up a large part of the mass.

The analysis is as follows:

Fe	88·05
Ni	10·37
Co	·68
Cu	·04
P	·21
S	·08
Si	·02
	99·45

Laboratory U. S. Geological Survey, March, 1890.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *On the Determination of Gas volumes by Direct Reading.*—A very simple apparatus has been contrived by Lunge which he calls a "gas-volumeter," by means of which the volume at normal pressure and temperature of the gas set free in any reaction can be read directly without requiring reduction. In its complete form, the apparatus consists of three tubes called respectively the measuring tube, the reduction tube, and the pressure tube. The measuring tube is graduated, and is closed at top by a two-way tap, one opening being to the air and the other into a lateral tube connected with the gas evolution apparatus. The reduction tube is enlarged at the upper end and is closed by a well fitting tap. The pressure tube is open above. All these tubes are drawn out below, so that strong rubber tubes can be slipped over them. By means of a Y-tube of glass the pressure tube is connected with the other tubes. The two taps being open, mercury is poured into the pressure tube, previously moistened, which of course rises in the other tubes. The barometer and thermometer are then noted, the height of the barometer corrected for the temperature and the pressure of aqueous vapor, and the volume which 100 c. c. of air would occupy at the resulting pressure and temperature is calculated. The pressure tube is then so adjusted in height that the mercury in the reduction tube (graduated for this purpose from 110 to 130 c. c.) stands at the division which represents the volume of 100 c. c. at the actually corrected pressure and temperature, when the tap on the reduction tube is closed. This tube is thus made to enclose once for all a quantity of air such that when the temperature is 0° and the pressure 760^{mm}, the air being dry, it shall occupy 100 c. c. By raising the pressure tube the measuring tube is filled with mercury and the evolution of gas into it is proceeded with as usual. To measure it, after the apparatus has acquired the temperature of the room, the division 100 on the reduction tube is made some-

what higher than the mercury level in the measuring tube, and the pressure tube is raised until the mercury in the reduction tube exactly reaches the 100 mark. If now the measuring tube be raised until the mercury within it is at exactly the same level as that in the reduction tube, it is evident that the gas it contains occupies the volume which it would have at 0° and under 760^{mm} pressure, since this is the condition of the air in the reduction tube which communicates with it. Hence the corrected volume can be read off at once on the measuring tube. Various modifications of the form of the apparatus for special cases are described. —*Ber. Berl. Chem. Ges.*, xxiii, 440, March, 1890. G. F. B.

2. *On the Nature of Solutions.*—Pickering has published an extended paper on the nature of solutions, as elucidated by a study of the density, electric conductivity, heat-capacity, heat of dissolution and expansion by heat of sulphuric acid solutions, following the suggestion of Mendeléeff that by plotting the rate of change, i. e., the first differential coefficient of the density, conductivity, etc., of the solution as a function of the percentage composition, any sudden alterations in the curvature might be more satisfactorily established. But the statement of Mendeléeff that the derivative yielded a straight line or a series of straight lines, was found to be true not of the first but only of the second derivative. The curves for example which represent the first differential coefficient of the densities of sulphuric acid solutions, though continuous, are made up of a series of separate curves which on further differentiation yield a series of straight lines. So if the contractions obtained on mixing sulphuric acid and water be plotted instead of the densities, while a curve totally unlike that of the densities is obtained, yielding a first derivative curve also unlike that of the densities, the second derivative yields a right line closely resembling the second derivative of the densities and indicating the existence of changes at the same points. In the same way the electric conductivities, heat-capacities, heats of dilution, and expansions are represented by curves which split up by two differentiations into a series of straight lines, showing changes at the same points. These points correspond to simple and definite hydrates of sulphuric acid amounting to as many as 17, the mono-hydrate being at one extreme and a hydrate with 5,000 H_2O being at the other. "The main facts elucidated by this work," the author says, "afford absolute proof that the properties of solutions do not vary regularly with their composition, and that the nature of the solution is therefore not merely physical. There can be no doubt but that solutions consist of hydrates of a definite composition, though these may always be in a state of partial dissociation."—*J. Chem. Soc.*, lvii, 64, March, 1890. G. F. B.

3. *On the Density of Fluorine.*—By using a larger apparatus in the preparation of fluorine by electrolysis and by purifying the gas from hydrogen fluoride by passing it first through a platinum worm cooled to −50° by means of methyl chloride and then through a

platinum tube containing anhydrous sodium fluoride (since it is not hygroscopic is preferable to the potassium salt), MOISSAN has been able to determine the density of fluorine. The pure gas was collected in platinum flasks of about 100 c. c. capacity, previously filled with nitrogen. After weighing, the fluorine was brought in contact with water and the evolved gases were measured and analyzed, a correction being made for any remaining nitrogen. The mean density found was 1·265, while that required by theory (F=19) is 1·316.—*C. R.*, cix, 861; *J. Chem. Soc.*, lviii, 201, March, 1890. G. F. B.

4. *On the Determination of Oxygen dissolved in Water.*—THRESH has proposed a new method of determining the oxygen which is dissolved in water, founded on the fact that a very minute quantity of a nitrite is able to cause the liberation of a very large amount of iodine when to a water containing it and oxygen, potassium iodide and sulphuric acid are added; the nitrogen oxide seeming to act as a carrier. Since the iodine thus set free is capable of accurate estimation, the oxygen dissolved in a drinking water may be very rapidly determined in this way and with great precision. For this purpose it is necessary simply to add to a known volume of the water a definite quantity of sodium nitrite together with an excess of potassium iodide and sulphuric acid, and, avoiding access of air, to determine volumetrically the amount of iodine liberated. Deducting the quantity corresponding to the nitrite used, the remainder represents the oxygen dissolved in the water. The strength of the solutions used and the apparatus employed in the determination are noted in the paper.—*J. Chem. Soc.*, lvii, 185, March, 1890. G. F. B.

5. *On a Method of distinguishing Hydrogen Arsenide from Hydrogen Antimonide.*—BRUNN has observed that hydrogen sulphide and hydrogen arsenide do not act on each other in the absence of air either in the gaseous state or in solution in water, even on exposure to direct sunlight; but that on the admission of air, arsenous sulphide is at once produced, and in both cases, a mixture of hydrogen arsenide and air in a flask over water deposited a brown-black precipitate; thus confirming the observation of Janowsky. But the author shows that this precipitate varies in its composition according to the amount of oxygen present. With an excess of air the hydrogen arsenide is oxidized to black metallic arsenic; while if only a small quantity of air be mixed with the gas, it is oxidized only to brown solid hydrogen arsenide. Hence it would appear that the above reaction of H_2S upon H_3As takes place in two stages; the H_3As being oxidized to arsenic in the first; and in the second the arsenic being converted into sulphide. On heating a mixture of hydrogen arsenide and hydrogen sulphide, however, to 230°, even when absolutely free of air, decomposition takes place and arsenous sulphide is deposited. Further experiment showed that hydrogen arsenide is itself decomposed at about this temperature, and that therefore the formation of arsenous sulphide is a secondary

reaction. Hydrogen antimonide, on the other hand, is at once decomposed by hydrogen sulphide even when both air and light are absent. If hydrogen antimonide be heated alone it begins to dissociate at about 150°. This fact the author proposes to use for the detection of traces of hydrogen antimonide occurring with hydrogen arsenide in hydrogen or other gases. For this purpose, the mixture of gases is to be passed through a tube about a meter long, heated to 208°–210°; in a liquid having this boiling point. No arsenic whatever is deposited, while all the antimony is thrown down. The mirror obtained may be examined in the usual way.—*Ber. Berl. Chem. Ges.*, xxii, 3202, Jan., 1890; *J. Chem. Soc.*, lviii, 209, March, 1890. G. F. B.

6. *On the Atomic Mass of Gold.*—MALLET's final paper on the atomic mass of gold has been presented to the Royal Society. The gold employed consisted (1) of material purified by himself, the final reduction being effected with formic acid; (2) of material furnished from the Philadelphia mint; (3) of material obtained from the New York assay office; and (4) of material sent to him from the British mint. The results appear to have been sensibly the same by each method for all the gold used. Seven series of experiments are described. In the first, auric chloride was precipitated with sulphurous acid and the gold weighed; and, in the resulting solution, the chlorine was determined. In the second, auric bromide was similarly treated. In the third, a potassium auri-bromide solution was divided into two equal parts, in one of which the gold was precipitated and weighed and in the other the bromine was determined. In the fourth, tri-methyl-ammonium auri-chloride was ignited and the metallic residue weighed. In the fifth, an attempt was made to determine the ratio between the weights of metallic gold and metallic silver deposited by the passage of the same electric current through their solutions. In the sixth, the electro-deposited gold was compared with the hydrogen set free by the same current. And in the seventh, the gold was precipitated by metallic zinc, and weighed, the hydrogen evolved by the excess of zinc being noted. The mean of the first series is 196·722; 2d, 196·790; 3d, 196·775; 4th, 197·225; 5th, 196·823; 6th, 197·137; and 7th, 196·897; the general mean being 196·910.—*Phil. Trans.*, clxxx, A. 395, November, 1889. G. F. B.

7. *On Musical Tones by means of unlike formed Waves.*—DR. RUDOLPH KÖNIG shows, by a series of rotating wheels, in which the intervals between the teeth are the same but of different form, that the tones produced by the rotation of these teeth against a suitable vibrator are musical and do not obliterate the fundamental tone produced by the main serrations of the wheel, and can produce a musical note as long as the dissimilarity in form does not change the amplitude of the fundamental waves. A number of diagrams of the serrated wheels accompany the paper.—*Wied. Ann. der Physik und Chemie*, No. 3, 1890, pp. 403–411. J. T.

8. *Electrical Vibrations in rarefied air without Electrodes.*—JAMES MOSER gives the following results of his experiments:—A glass tube which contained a gas of constant rarefaction was surrounded by a wider tube, and the rarefaction varied in this by means of the air pump. The following results were obtained:—

(*a.*) At the ordinary atmospheric pressure in the outer tube the inner tube becomes luminous.

(*b.*) With a sufficient rarefaction of the outer tube the phenomenon is reversed: the inner tube becomes dark and the outer one luminous. Here there is a screening action.

(*c.*) The rarefaction was pushed further, the outer tube became dark, the inner one luminous, so that to the eye the third stage was like the first one.

The more perfect vacuum gives, therefore, no screening action. It has lost the power of conducting the electrical current.—*Phil. Mag.*, April, 1890, p. 375. J. T.

9. *Magnetization in strong fields at different temperatures.*—H. E. J. G. DUBOIS believes that his experiments show that all doubts that have occasionally arisen in regard to the existence of a limit of magnetization will be dissipated. He agrees with the results of M. Goldhammer, that "magnetization affects all physical properties of metals in a way generally depending on its direction. Whenever the ensuing changes are odd functions of the magnetization (both simultaneously reversing their sign), they are simply proportional to it. In the case of even functions (always having the same sign), they are simply proportional to its square.—*Phil. Mag.*, April, 1890, pp. 293–306. J. T.

10. *On the structure of the Line Spectra of the Chemical Elements.*—J. R. RYDBERG, of the University of Lund, gives the following as the results of his study:

(1.) The long lines of the spectra form doublets or triplets, in which the difference (ν) of wave numbers of their corresponding components is a constant for each element.

(2.) The corresponding components of the doublets form series of which the terms are functions of the consecutive integers. Each series is expressed approximately by an equation of the form $n = n_0 - \frac{N_0}{(m+\mu)^2}$, where n is the wave number, m any positive integer (the number of the term), N_0, n_0 and μ constants peculiar to the series.

The wave length (and the wave numbers) of corresponding lines, as well as the values of the constants ν, n_0, μ of corresponding series of different elements, are periodical functions of the atomic weight.—*Phil. Mag.*, April, 1890, pp. 331–337. J. T.

11. *Velocity of the Propagation of Gravitation.*—M. J. VAN HEPPERGER, in a paper read before the Vienna Academy of Sciences, has assigned an inferior limit to the velocity of propagation of gravitation. It results from this limit that the time taken by gravitation to travel the radius of the earth's orbit does not exceed a second.—*Nature*, March 20, 1890, p. 472. J. T.

12. *Electricity in Modern Life;* by G. W. DE TUNZELMANN. 272 pp. 8vo. London, 1889. (Walter Scott.)—The widespread interest in electricity and its applications during the past decade or two has called out a large number of books, of varying scope and method, devoted to the different parts of the subject. The present volume starts with the design to present the matter in such a form as to be attractive and intelligible to the ordinary reader with little or no scientific training, and this plan is carried through with satisfactory success. On many topics, such as the telegraph, the telephone and telephone exchanges, electric lighting, etc., the reader will find information of interest here, which is not always easily accessible elsewhere.

II. GEOLOGY.

1. *The Coal formation in southeastern England.*—Professor W. BOYD-DAWKINS has recently reported on the results of a boring at Dover, opposite Calais, which was commenced in 1886, on his recommendation, by the South-Eastern Railway and Channel Tunnel Company. The coal measures were reached at a depth of 1204 feet, and good coal was found 20 feet below. Much is expected from further exploration. At Calais, the coal-measures had previously been reached at a depth of 1104 feet. The coal area extends thence along the boundary of France and Belgium. The Westphalian field is 7218 feet thick and contains 117 coal beds yielding 294 feet of workable coal; at Liège the thickness is 7600 feet, the number of coal beds 86, the thickness of good coal 212 feet; at Monz these figures are 9400, 110, 250; in Somersetshire southeast of South Wales, 8400 feet, 55 and 98; in South Wales, 1100, 75 and 120. The coal-measures are represented as upturned and lying unconformably beneath the Oölitic and Cretaceous strata.

The probable existence of the coal-measures in southeastern England was first urged by Godwin-Austen in 1856, who showed that the coal fields of South Wales in North Somerset and the Belgian were characterized by long, narrow, east and west folds and lay in nearly the same line; and pointed out the Thames Valley and the Weald of Kent and Sussex as places where they possibly might be discovered. Professor Prestwich, of the Coal-commission of 1856–71, reported in favor of this conclusion, and with full details as to the probable facts. A well was consequently bored in 1871 by the Sub-Wealden Exploration Committee at Netherfield, in the Wealden region; but at a depth of 1905 feet it was stopped after passing only 60 feet into the Oxford clay. Eleven years later an anticlinal of Devonian and Silurian was found in a boring in the area of London at Ware at a depth of about 800 feet, and near Richmond at a depth of 1289 feet, with the oolite unconformably superposed only 87 feet thick, indicating as Professor Boyd-Dawkins states, that coal should be looked for in the synclinal band farther south; and there it was found.

2. *Geological Society of America.*—The publication of the papers read before the Geological Society at its December meeting has been going forward, and already have appeared papers by I. C. Russell, the Surface Geology of Alaska; A. C. Lawson, Canada Archæan surfaces and taxonomy; W. M. Davis, structure and origin of Glacial Sand-plains; C. R. VanHise, the pre-Cambrian of the Black Hills; S. F. Emmons, Orographic movements in the Rocky Mountains; R. Bell, Glacial phenomena in Canada; Sir W. Dawson and D. P. Penhallow, the Pleistocene flora of Canada; C. D. Walcott, the value of the term Hudson River group in geological nomenclature; A. Winchell, Some results of Archæan studies.

3. *Quaternary History of Mono Valley, California*, by Israel C. Russell. 126 pp. large 8vo. 8th Ann. Rep. Director U. S. Geol. Survey for 1866-67 (yet unpublished).—Mr. Russell's extensive explorations over the Great Basin, as shown in his Reports on Lake Lahontan Basin, and the Glaciers of the Sierras, had well prepared him for his later work on the Quaternary history of the Mono Valley. This valley of Mono Lake is situated on the southwestern part of the basin, 6,380 feet above the sea. In Mr. Russell's account of the region, he first describes its general features, those of the present time and of the Quarternary, its remarkable tufa towers and other deposits, and the chemistry of its waters; and then takes up, and treats with much instructive and interesting detail its glacial history. Among the facts mentioned, he states that the basin of Lake Mono is rock-bound on all sides, and therefore must have been excavated by glacial abrasion; the bottom is now fifty-one feet below the surface of the lake. Next the volcanic history is discussed. Scores of recent craters of basalt, andesite and more recent lavas are described as occurring along the base of the Sierra in the vicinity of Lake Mono; and not far distant to the eastward are mountain ranges of "more ancient volcanic rocks;" but no such cones occur in the adjoining part of the Sierra. Feeble fumaroles and springs of heated water occur at Hot Spring Cove on the eastern side of Paoha Island as the only remains of former activity.

The region described is one of the most interesting on the Pacific side of the Continent, as shown some years since by Prof. LeConte's descriptions. The fuller details and judicious discussions of Mr. Russell's memoir bring the fact strongly to view. This is made the more manifest by the many excellent maps and views.

4. *Catalogue of British Fossil Vertebrata;* by Woodward and Sherborn. (Communicated.)—Some months since Mr. Arthur Smith Woodward published the first part of a Catalogue of the fossil fishes in the British Museum, forming a volume of nearly 500 pages, octavo, with 17 plates. This volume contained only the Elasmobranchii; and we may soon expect another which shall include the Placoderms, Ganoids and Teleosts. Much conscientious labor was bestowed upon this work by Mr. Wood-

ward, and containing as it does complete synonymy and copious reference to authorities in addition to the enumeration of the specimens in the British Museum, it cannot fail to be of great utility not only to the frequenters of the Museum but to students of fossil Ichthyology in all countries.

Now, Mr. Woodward, with the coöperation of Charles Davies Sherborn, has issued a smaller volume which is a *Catalogue raisonné* of all the fossil vertebrates up to the present time found in the British Islands. The introduction to the volume includes much useful and interesting information in regard to their geographical and stratigraphical distribution, with tables of the dates of the different parts of the "Poissons Fossiles" of Agassiz and of the "Odontography" of Professor Owen. The catalogue which follows give not only full synonymy, but a bibliography which must have cost the authors much time and trouble. It also attempts a revision of the genera, which on the whole is judicious and will be a great help to the student, and yet in some repects is too revolutionary and will tend to confuse where it aims to make clear. This is specially true of the references to American genera, which would have been more satisfactory if the authors had been in possession of good specimens, and had not trusted to necessarily imperfect figures and descriptions. It is natural and unavoidable that those who are reviewing genera and species of fossils found in other countries should err in considering forms allied to those with which they are familiar at home as identical or mere varieties; the material under their eyes attaching to itself the solitary or scattered specimens floating through foreign literature by an attraction which is directly as the mass. Hence a safe and satisfactory comparison can only be made when approximately equal amounts of foreign material have been studied with that of home origin, and the prevailing and characteristic features of each group are given their due weight. Fortunately, Mr. Woodward is soon to be in America, where he comes to see with his own eyes the fossil fishes found in this country to which he has made reference in the works referred to above. We may fairly expect that with the things themselves before him he will modify somewhat the opinions he has formed simply from figures and descriptions; and it will be not only a gratification to his American co-laborers but a decided gain to science when with his keen observation and great knowledge he shall pass their material in review. J. S. N.

5. *The Mammalia of the Uinta formation.* 112 pp. 4to. Trans. Amer. Phil. Soc., 1889. *On the Geological and Faunal relations, and on the Creadonta, Rodentia and Artiodactyla;* by Wm. B. Scott, of Princeton; *and on the Perissodactyla and the Evolution of the Ungulate foot;* by H. F. Osborn, of Princeton.—Professor Scott discusses the stratigraphical relations of the Uinta and other Eocene formations of the Rocky Mountain summit region, and concludes that this group (so named, not by Mr. King to whom it is credited but by Professor Marsh) is, as generally believed,

the most recent. From the Bridger Fauna it differs in the absence of Dinocerata and Tillodonts. The authors describe several new species of fossil Mammals from the Uinta beds, and illustrate them by a number of plates of excellent figures.

6. *On the Lower Carboniferous limestone series in Central Texas;* by R. S. TARR.—Mr. Tarr, in a recent communication to the editors, gives an account of his study of a Paleozoic region in Central Texas which was reported upon by Dr. F. Roemer in 1848 as affording fossils like those of the Carboniferous limestones of the Mississippi Valley. The fossils described were from San Saba County. Mr. Tarr reports that the Paleozoic area covers part of Llano, Mason, Southern San Saba and McCulloch Counties. The older rocks in it are much upturned and flexed; and the Silurian limestones are chiefly marble, and have lost most of their fossils by metamorphism. Carboniferous limestones and shales overlie these beds unconformably, and the Upper Carboniferous consisting of sandstones, shales, clays and limestone, "attain a thickness in one section of 8,000 feet."

7. *The Geographic Development of Northern New Jersey,* by WM. M. DAVIS and J. WALTER WOOD, Jr. (Proc. Boston Soc. N. Hist., 60 pp. 8vo. 1889.)—This paper is a valuable study in the subject of the development of drainage channels and areas and of topographic features.

8. *The Intrusive and Extrusive Trap sheets of the Connecticut Valley;* by WM. M. DAVIS and C. L. WHITTLE. (Bull. Mus. Comp. Zool., xvi, No. 6, Dec., 1889).—The authors here treat of the means of distinguishing Intrusions and Extrusions, and their general features in Connecticut, and describe in detail some of the more important localities. To those who have read the paper of E. O. Hovey in the number of this Journal for last November (a month earlier in time of publication) and desire the most recent views of Prof. Davis on the general question and help as to methods of further investigation, this paper will have special interest.

9. *Underground Water in the Western Districts of New South Wales;* by H. C. RUSSELL, F.R.S.—With reference to the remarkable supply of underground water in the interior of Australia, Mr. Russell states that Darling River, one of the largest of the rivers, whose drainage-area receives 22·14 inches of rain (mean result of ten years) discharges only 1½ per cent of the amount. This remarkably small proportion is due to the porous character of the rocks, through which the water becomes subterranean. Lake George, a lake 5 × 16 miles in area at high water, situated in a depression in the mountains about 2200 feet above mean tide-level, receives by drainage from the hills around but 2 to 3·64 per cent of the rain-fall. The great porosity of the rocks is here again demonstrated.—*Journ. Proc. R. Soc. N. S. Wales,* xxiii, 57, 1889.

10. *Genesis and Chemical Composition of the Italian Volcanic soils;* by Dr. LEONARDO RICCIARDI, Prof. Chim. Accad. Agricolt.

di Torino. 150 pp. 8vo. Florence, 1889.—Dr. Ricciardi here treats of the various volcanic rocks of Italy, gives their chemical composition, distribution, the results of their decomposition and the character of the soils they afford. He discusses the effects of atmospheric agents in producing decomposition and among them those of vegetation, the Lichens, Diatoms, and Bacteria. One of the most characteristic lichens of volcanic regions, the *Stereocaulon Vesuvianum*, afforded in two analyses, one of them of specimens from the Leucitic lava of Vesuvius:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	P_2O_5
1.	46·40	11·13	....	20·40	2·51	14·78	....	2·28	tr.=97·49
2.	46·41	19·67	6·88	4·17	5·28	10·53	2·02	4·09	=99·00

The amount of ash is stated to be 11·16 p. c. of the dried lichen. Special soils of various localities are next described in detail and their origin considered.

11. *Fauna der Gaskohle, etc., Der Permformation Bohmens.* Band ii, Heft 4. Prague, 1889. Dr. Ant. Fritsch.—Dr. Fritsch's work on the Vertebrate fossils of the Permian or Upper Carboniferous of Bohemia has long been favorably known to geologists. The earlier parts, on the Batrachians of the order *Stegocephala* and its allies, have added very much to our knowledge of this group, and the later parts on the fishes prove equally interesting, as illustrating some of these in a much more perfect manner than has hitherto been possible. Vol. ii, pt. 3, published in 1848, describes the *Dipnoi*, and in part 4, just issued, the author is enabled to restore a species of *Ctenodus* (*C. tardus*) in such a manner as to bring out very distinctly its remarkable resemblance to the modern Barramunda of Australia (*Ceratodus*). It is most interesting to see these fish, hitherto mostly known by detached teeth, thus restored and compared in their details with their more modern relatives, as well as with those of the Devonian and Silurian. The figures also throw much light on curious bones and scales found with the *Ctenodus* teeth, with which collectors in the Carboniferous are familiar.

Part 4 is devoted principally to another group, the sharks of the genus *Orthacanthus* Agassiz, a genus established by the great worker in Paleozoic fishes for a group of straight, striated spines often with denticles near their points, but which it now appears is synonymous with the genus *Diplodus* of the same author founded on the teeth. Egerton, Newberry, Cope and others have remarked on the probable identity of the two genera, from the occurrence of *Orthacanthus* spines and *Diplodus* teeth in the same beds. The writer, before knowing anything of the views of these authors, stated in 1869 a similar conclusion from the frequent association of the spines and teeth on the shales of the Pictou coal field in Nova Scotia.*

Fritsch now presents us with illustrations of specimens in which the cartilaginous skull and jaws are in great part preserved,

* Second edition of Acadian Geology, p. 211.

and the rows of small teeth and the great nuchal spine are seen in place or nearly so; and we see that the teeth lie flat on the jaw in successive rows as in modern sharks. We see also that there were bands of very small teeth on the gill-arches quite different in form from those of the jaws, and that the latter are of different forms in different parts of the mouth, so that if found separated they might be referred to distinct species.

These specimens enable true species to be established, as distinguished from those founded merely on detached teeth and spines, and of these four are described and figured, besides a doubtful one, and spines of the allied genera, *Tubulacanthus* and *Brachyacanthus*, etc.

These Carboniferous sharks, of moderate size and armed with sharp teeth, must have devoured the smaller ganoids of the estuaries and lagoons, and probably also the larvæ of Batrachians, and the smaller aquatic species of these animals. *Coprolites* which are found in the same beds are usually filled with the scales of small ganoids. Both in America and in Europe the abundance of spines and teeth in some of the coal shales testifies to the numbers of these predaceous fishes, and the presence of their teeth in the roofs of coal beds, and even in some cases in the coal itself, shows that they ventured into fresh water and even into the shallower ponds of the coal swamps.

Fritsch deserves the utmost credit for his painstaking and careful work on these fossils, and his work should be in the hands of all students of Carboniferous batrachians and fishes. J. W. D.

12. *On fossil plants collected by Mr. R. A. McConnell on Mackenzie River and by Mr. T. C. Weston on Bow River;* by Sir J. William Dawson. Trans. Roy. Soc. Canada, vol. vii, sect. iv, 1889.—Twelve species are here enumerated, two of which are new, the remainder having been found in some of the Arctic localities. Of the remainder, seven have previously been found in the Mackenzie River region, all but one of which are also common to the Fort Union series along the 49th parallel, pointing strongly to the close relationship between the Mackenzie River beds and those of the Fort Union group.

The fine oak leaf collected by Mr. Weston at Calgary (Fort Union) is probably correctly referred to *Quercus platania;* but the specimen figured by Professor Lesquereux in his "Tertiary Flora," which comes from Carbon, Wyoming, is probably not that species, being a palminerved leaf. In this paper Sir William Dawson manifests a willingness to regard the Fort Union group as belonging to the Tertiary system, while admitting that it forms a part of the Laramie series in general, the lower portion of which is conceded to be Cretaceous. L. F. W.

13. *The Bala Volcanic Rocks of Caernarvonshire and associated rocks,* being the Sedgwick prize essay for 1888, by Alfred Harker, M.A., F.G.S., Demonstrator in Geology (Petrology) in the University of Cambridge. 130 pp., 8vo.—This memoir contains the results of a careful stratigraphical and petrological study

of the rocks referred to in the title. The rocks are rhyolytes, augite-andesytes, diabase, gabbro, hornblende-diabases, hornblende-picryte, and others. Their origin, the nature of the crust-movements leading to the volcanic irruptions, the following of the lighter acidic lavas by the heavier basic, are among the subjects discussed.

14. *Scapolite Rock.*—Professor F. L. NASON, of New Brunswick, N. J., states in a letter of April 5th, that he has found, associated with the crystalline limestone of Vernon, Franklin Furnace, and Sparta, New Jersey, a Scapolite rock, consisting of scapolite, hornblende, pyroxene and orthoclase. The rock is usually well foliated. Titanite is rather abundant in the rock.

III. BOTANY AND ZOOLOGY.

1. *Histology as a Basis for Classification.*—At the Botanical Congress held in Paris, on the 24th of August, and now pretty fully reported in the Bulletin de la Société Botanique de France, there was an elaborate paper by Vesque, in which he supported by additional instances the claims of Microscopic Anatomy as a factor in Systematic Botany. The positions taken by Vesque were contested by many disputants, one of the more important opposing communications being from Cornu. G. L. G.

2. *On the Stem Structure of Iodes Tomentilla;* by B. L. ROBINSON. (Ann. du Jardin Botanique de Buitenzorg., vol. VIII, p. 95).—In this interesting paper Mr. Robinson treats of the anomalous histological features of the species mentioned in the heading, and takes up also certain other members of the Order *Phytocreneæ* to which it belongs. Some of the morphological features are elucidated with much skill. G. L. G.

3. *Garnsey's Translation of Sachs's History of Botany.*—When the German edition of this interesting work appeared, we took occasion to give in this Journal an extended review of its chief features. It is therefore unnecessary to go over the same outlines again. It is, however, due to the translators to say that his work has been remarkably well done and that it brings out clearly the attractive style of the German teacher. Some slight mistakes which were attributable to careless proof-reading or transcription in the original have been carefully corrected, and the English edition is uncommonly free from errors. The naïve preface by Professor Sachs to this translation is well worth giving almost in full, since it sums up well a few of the changes which his views experienced after the publication of the works of Darwin on the movements of plants, and certain other treatises which controverted positions held by him.

"On questions connected with times long gone by, the decision of the experts has in most cases been already given, though I myself found to my surprise that older authors had for centuries been regarded as the founders of views which they had distinctly repudiated as absurd, showing how necessary it is that the works

of our predecessors should from time to time be carefully read and compared together. But in the majority of cases there is no dispute at the present day respecting the historical value, that is the operative influence on posterity, of works written three hundred or even one hundred years ago.

"But it is a very different matter when the author of a book like mine ventures, as I have done for sufficient reasons, but at the same time with regret, to sit in judgment on the works of men of research and experts, who belong to our own time, and who exert a lively influence on their generation. In this case the author can no longer appeal to the consentient opinion of his contemporaries; he finds them divided into parties, and involuntarily belongs to a party himself. But it is a still more weighty consideration that he may subsequently change his own point of view, and may arrive at a more profound insight into the value of the works which he has criticised; continued study and maturer years may teach him that he overestimated some things fifteen or twenty years ago, and perhaps undervalued others, and facts, once assumed to be well established, may now be acknowledged to be incorrect.

"Thus it has happened in my own case also in some but not in many instances, in which I have had to express an opinion respecting the character of works which appeared after 1860, and which to some extent influenced my judgment on the years immediately preceding them. But this was from fifteen to eighteen years ago when I was working at my History. It might perhaps be expected that I should remove all such expressions of opinion from the work before it is translated. In some few cases, in which this could be effected by simply drawing the pen through a few lines, I have so done; but it appeared to me that to alter with anxious care every sentence which I should put into a different form at the present day would serve no good purpose, for I came to the conclusion that my book itself may be regarded as a historical fact, and that the kindly and indulgent reader may even be glad to know what one, who has lived wholly in the science and taken an interest in everything in it old and new, thought from fifteen to eighteen years ago of the then reigning theories, representing as he did the view of the majority of his fellow botanists.

"However these remarks relate only to two famous writers on the subjects with which this History is concerned. If the work had been brought to a close with the year 1850 instead of 1860 I should have hardly found it necessary to give them so prominent a position in it. Their names are Charles Darwin and Karl Nägeli. I would desire that whoever reads what I have written on Charles Darwin in the present work should consider that it contains a large infusion of youthful enthusiasm still remaining from the year 1859 when the Origin of Species delivered us from the unlucky dogma of constancy.

"Darwin's later writings have not inspired me with the like feeling. So it has been with regard to Nägeli. He, like Hugo

von Mohl, was one of the first among German botanists who introduced into the study that strict method of thought which had long prevailed in physics, chemistry, and astronomy; but the researches of the last ten or twelve years have unfortunately shown that Nägeli's method has been applied to facts which, as facts, were inaccurately observed. Darwin collected innumerable facts from the literature in support of an idea, Nägeli applied his strict logic to observations which were in part untrustworthy. The services which each of these men rendered to the science are still acknowledged; but my estimate of their importance for its advance would differ materially at the present moment from that contained in my History of Botany. At the same time I rejoice in being able to say that I may sometimes have overrated the merits of distinguished men, but have never knowingly underestimated them." G. L. G.

4. *On the Compound eyes of the Arthropoda;* by J. M. Clarke. (Communication dated Albany, March 1st, 1890.)—The recent (February, 1890), number of *Studies from the Biological Laboratory* of the Johns Hopkins University contains a very interesting paper by Dr. S. Watase on the morphology of the compound eyes in the Arthropoda. The developmental and mature characters of the optical unit or ommatidium are shown for Serolis, Talorchestia, Cambarus, Callinectes and Limulus (lateral eyes). In the last named, the ommatidia are covered by a simple layer of integumentary chitin, the cornea, which is thickened over the opening of each eyelet, forming a simple dioptric organ or lens. Thus the inner surface of the cornea of Limulus is covered by a multitude of minute elevations, corresponding numerically to the ommatidial cavities. In Serolis, representing the Isopod type of compound eye, a discrete portion of the chitin is enclosed within the ommatidial cavity forming a subspherical crystalline cone. Dr. Watase suggests in a foot-note that the structure of the eye in Phacops, which I endeavored to elaborate in the Journal of Morphology, vol. ii, No. 2, appears to correspond more closely with that of Serolis and the Isopods than with that of Limulus. After reading this admirable paper I have no longer any doubt that the type of trilobite-eye which was termed by me *holochroal* (exemplified by Asaphus, Proëtus, and in fact nearly all trilobites except the Phacopidæ and Harpidæ), is essentially identical with that of Limulus; but I am not prepared to concede the similarity between the *schizochroal* eye (Phacops) and that of Serolis. It would simplify the correlation of what is known in regard to the schizochroal trilobite-eye if we were entitled to assume, as does Dr. Watase and as was done by Quenstedt and Burmeister, that a chitinous envelope originally covered the entire visual surface but has invariably been lost; this, however, I do not believe is any longer a legimate assumption. No trace or evidence of such a continuous corneal envelope has ever been seen, though these fossils have been under the most careful scrutiny for over fifty years. I have myself exam-

ined a vast number of specimens in almost every variety of preservation, with the very purpose of determining the question of its existence, and I am satisfied that the cornea never existed save as discrete, hollow corneal lenses, for however tenuous an additional continuous layer may have been it would not have been so delicate as to have escaped preservation in some of the conditions observed. Again, it must not be overlooked that in the compound eye of Phacops are continuous patches of scleral integument between the ommatidia, a fact which finds no homology among recent Arthropod eyes nor in the holochroal trilobites. The eyelets are absolutely and widely discrete, while in Serolis, Limulus they are in the closest apposition. More evidence is needed to prove that the schizachroal type of compound eye is still extant. An interesting suggestion bearing upon its genesis, and one which may fruitfully be followed up, is that (as remarked in a foot-note to my paper referred to) an extremely young individual of Calymene (holochroal) showed remarkably large corneal lenses and an interlensar sclera developed to such a degree as I have never observed among mature holochroal eyes.

J. M. C.

5. *Prodromus Faunæ Mediterraneæ, sive Descriptio Animalium Maris Mediterranei Incolarum, etc., congessit* J. V. CARUS, vol. ii, Pars I, BRACHIOSTOMATA, MOLLUSCA. Stuttgart, 1889. [E. Schweizerbartsche Verlagshandlung, E. Koch.]—This first part of the second volume of Dr. Carus's work on the Mediterranean Fauna extends to the close of p. 272. The Brachiostomata include Class 1, containing the Bryozoa, which occupy 54 pages, and Class 2, the Brachiopoda, covering 7 pages. The Brachiopoda include 3 species of Terebratula, 2 of Terebratulina, 2 of Waldheimia, 1 of Megerlia, 2 of Platydia, 3 of Argiope, 5 of Cistella, 1 of Thecidea, 1 of Rhynchonella, and 3 of Crania. After these, descriptions of the Mollusca follow, commencing with the Pelecypoda or Lamellibranchiates.

6. *Corals and Coral Islands;* by J. D. DANA. 3d edition. New York: Dodd, Mead & Co.—This new edition of the Corals and Coral Islands, announced on page 326, has now been published. The map of the Louisiade Archipelago will be found to be a very complete argument in favor of the Darwinian theory of subsidence. The size of the barrier reef—150 miles long—the great interior sea, and the fragment-like deeply indented islands and islets within, appear to admit of no other explanation. In the discussion of opposing arguments, Dr. Guppy's current theory is shown to be inapplicable to the largest of coral island archipelagos, because the needed currents do not exist. A map of part of southern Oahu, showing the positions of the artesian borings and the accompanying descriptions give the basis now available for conclusions with regard to the origin of the great thickness of the shore reefs. The great coral-reef sand-accumulations of Florida, the Bahamas and the Bermudas, reaching a height of 230 feet in the latter region, which all recent observers

describe as made of drifted sands, and which contrast strikingly with facts in the Central Pacific, are explained by reference to the positions of the areas within the cyclone belt of the ocean. A copy of the map of these regions by the Hydrographic department, making Plate XI, gives all the soundings of the adjoining seas. The four new colored plates, one representing Actiniæ, and the others, species of living corals, are from the author's Zoophyte Atlas.

IV. Astronomy.

1. *The Diurnal Variation of Terrestrial Magnetism;* by Arthur Schuster.—Prof. Schuster, in a memoir read before the Royal Philosophical Society of London, has discussed the Diurnal Variation of Terrestrial Magnetism, by the methods of Spherical Harmonics. For this he has used the observations for 1870 made at four stations, Greenwich, Lisbon, St. Petersburg and Bombay. He thus sums up the principal results obtained in his paper:—

(1.) The principal part of the diurnal variation is due to causes outside the Earth's surface, and probably to electric currents in our atmosphere.

(2.) Currents are induced in the Earth by the diurnal variation which produce a sensible effect chiefly in reducing the amplitude of the vertical component and increasing the amplitude of the horizontal component.

(3.) As regards the currents induced by the diurnal variation, the Earth does not behave as a uniformly-conducting sphere, but the upper layers must conduct less than the inner layers.

(4.) The horizontal movements in the atmosphere which must accompany a tidal action of the Sun or Moon, or any periodic variation of the barometer such as is actually observed, would produce electric currents in the atmosphere having magnetic effects similar in character to the observed daily variation.

(5.) If the variation is actually produced by the suggested cause, the atmosphere must be in that sensitive state in which, according to the author's experiments, there is no lower limit to the electromotive force producing a current.

2. *Bibliographie Générale de l'Astronomie;* by J. C. Houzeau and A. Lancaster.—The second volume of this large and very valuable Bibliography appeared several years ago (see this Journal, vol. xxi, p. 253, and vol. xxiv, p. 76). Two parts of vol. i have since been issued, the first in 1887, and the second in 1889. The first part contains an extended history of Astronomy (325 pages) by M. Houzeau. The history of the science in its earlier developments is more particularly dwelt upon. The remainder of this part is given to the Bibliography of the History of Astronomy and to Astrological Books. There are of these 5415 entries. A large number of these are manuscripts. When there are second editions, or translations, or detailed reviews of printed books, the titles of or references to them follow the first entry.

Before the appearance of the second part of the Bibliography M. Houzeau died, and an interesting biography of him by Mr. Lancaster is given as introduction thereto. M. Houzeau's life in this country in 1858–1866 and his life in Jamaica form portions of Mr. Lancaster's story. The subjects covered by this part are Biography and Correspondence; Didactic and general works; Spherical Astronomy; Theoretic Astronomy.

The third part of vol. I, which is in press, will contain Celestial Mechanics; Astronomical Physics; Practical Astronomy; Descriptive Astronomy; Systems. The second volume (already published) contained the bibliography of Memoirs and Notices; the third volume will be devoted to Observations.

V. Miscellaneous Scientific Intelligence.

1. *National Academy of Sciences.*—Papers entered to be read at the April meeting, 1890.

H. C. Wood: Effects of the inhalation of nitrogen, nitrous oxide, oxygen, and carbonic acid upon the circulation: with special reference to the nitrous oxides, anæsthesia and asphyxia.

A. A. Michelson: Application of interference methods to astronomical measurements.

S. H. Scudder: Physiognomy of American Tertiary Hemiptera.

D. P. Todd: Totality of the eclipse of 1889, December 22.

W. K. Brooks: The budding of Salpa considered in relation to the question of the inheritance of acquired characters.

G. Brown Goode and Tarleton H. Bean: Recent advances toward a knowledge of the fishes of the great oceanic depths.

S. C. Chandler: A system of classification of variable stars.

H. A. Rowland: On the spectrum of metals.

S. P. Langley: On the cheapest light.

R. Pumpelly: Relation of secular disintegration to certain crystalline and transitional schists; Structure of the Green Mountains.

T. Gill: The interrelationships of the Ichthyopsida; the Notacanthoid Fishes as representatives of a peculiar order; the Halosauroid Fishes typical of a special order.

Ira Remsen: Researches on the double halides; researches on the sulphinides.

2. *Great depth in the South Pacific Ocean.*—The bathymetric map published in the writer's work on Volcanoes, registers the depth of 4428 fathoms just south of the Friendly Islands. A bulletin from the Hydrographic Department of the Admiralty dated January, 1890, contains among the soundings of H. M. S. Egeria in 1889, one of 4530 fathoms to the southeast of that of 4428 fathoms, which is thus far the deepest found in the South Pacific. The records are as follows:

			Fathoms.	Temp. at bottom.	
Lat. 19° 31′ S.	173° 40′ W.		2235	34·6	volcanic mud.
19 16	173 38		1795	35·0	Globig. ooze.
18 24	173 02		2525	34·5	chocolate clay; Radiolarian ooze, pumice.
17 56¾	172 42½		3092	34·5	chocolate clay.
17 04	172 14½		4530	wire parted.	

Between the Phœnix and Union Groups, the following soundings were obtained:

Lat. 5° 21′ S.	171° 38¼′ W.	3312 fath.	Bottom temp.	34·5
5 58	171 23¾	3100	"	34·5
6 45	171 17½	2956	"	34·5
7 52	171 01½	2766	"	34·0
8 30¼	171 07½	2518	"	34·5
10 24½	171 20¼	2680	"	33·5

The first of the above soundings—nearly 20,000 feet—was obtained about 60 miles southwest of Sydney Island; and the last about half way between Fakaafo and Swain's Island.

Pteropod ooze was found in a number of soundings between the Friendly Islands and the Feejees, or near 179° W. and 20° to 21° S., at depths of 300 to 700 fathoms. J. D. D.

3. *Transactions of the Kansas Academy of Science*, 1887-88, vol. xi, 130 pp. 8vo.—This volume contains geological papers as follows: ROBERT HAY, on the horizon of the Dakota Lignite of Middle Kansas; E. N. S. BAILEY, on the newly-discovered salt beds in Ellsworth Co., Kansas; E. JAMESON, Geology of the Leavenworth Prospect Well; R. HAY, The Triassic Rocks of Kansas; Prof. F. H. SNOW, on reported (not actual) Nickel Mines in Logan Co.; E. N. S. BAILEY, Composition of Kansas Coals. The beds of rock salt reported on by Mr. Bailey occur at a depth of 730 feet in two layers, 50 and 90 feet in thickness, with 5 feet of gray slate intervening. An analysis proves it to contain 95 p. c. of pure salt. A similar bed has been struck at Hutchinson and brines are abundant from many borings.

4. *Loubat Prize of the Academy "Des Inscriptions et Belles-Lettres" of the Institut of France.*—This prize is established on a gift to the Academy by Mr. Loubat, of the New York Historical Society. The foundation affords an annual income of 1,000 francs for a prize of 3,000 francs, to be given triennially, for the best published work on the history, geography, archæology, ethnography, linguistics, numismatics, of North America. The extreme limit of time fixed by the Academy for the matters treated in the works submitted to the council is the date of 1776. The prize will be given first in 1892. Works published in Latin, French, English, Spanish and Italian after July, 1889, will be accepted. Two copies must be sent to the Secretary of the Institute before the 31st of December, 1891. Two other copies must be contributed by the "laureate" to the Academy under whose auspices the work is made a success, one to Columbia College, New York, and one to the Historical Society of the same city.

5. *Essays of an Americanist;* by DANIEL G. BRINTON. 490 pp. 8vo. Philadelphia, 1890. (Porter & Coates.)—These essays, based on Archæological American history have the headings: 1. Ethnologic and Archæologic; 2. Mythology and Folk lore; 3. Graphic Systems and Literature; 4. Linguistic. The discussions of the learned author extend to the questions of the origin of language, and the origin of the American people and their mythology.

Catalogue of Fossil Reptilia and Amphibia in the British Museum. Part III, containing the order Chelonia; by R. Lydekker. 239 pp. 8vo. London, 1889.

Index to the Reports of the Chief of Engineers, U. S. A., 1880–1887. 622 pp.

The topography of Florida by N. S. Shaler, Bull. Mus. Comp. Zool., Cambridge, vol. xvi. No. 7. 1890.

Studies on Lepidosteus, by E. L. Mark; 128 pp. 8vo, with nine fine plates. Ibid., vol. xix, No. 1, 1890.

History of Niagara River, by G. K. Gilbert. 24 pp. 8vo. Ann. Rep. Comm. State Reserv. Niagara for 1889.

Physical History of the Boston Basin, by W. O. Crosby. Boston, 1889.

Geology of the Lassen Peak District; by J. S. DILLER. 8th Ann. Rep. Director U. S. Geol. Survey. 32 pp. large 8vo. 1889.

Fossil Butterflies of Florissant; by S. H. Scudder, ibid. 32 pp. 8vo. 1889.—Mr. Scudder here describes and figures several new species, making the number from Florissant seven, which is nearly half of all the fossil species known.

Annals of the Astronomical Observatory of Harvard College, Edward C. Pickering, Director, vol. xxii: Meteorological Observations made on the summit of Pike's Peak (the height 14,434 feet), Colorado, Jan., 1874, to Jan., 1888, under the direction of the Chief Signal Officer, U. S. A., 476 pp. 4to.

Memoirs of the National Academy of Sciences.—Vol. IV; Part 2, just issued contains Contributions to Meteorology by E. Loomis (pp. 7–79); on the determination of Elliptic Orbits from three observations, by J. Willard Gibbs; the temperature of the moon, by S. P. Langley; the Lucayan Indians, by W. K. Brooks.

Bulletin of the American Museum of Natural History, Vol. II, Nos. 3, 4, contains several papers on new or described mammals of America, by F. M. Chapman; Birds and Mammals, by J. A. Allen; Mammals of New Mexico, by E. A. Mearns.

RICHARD OWEN.—Professor Richard Owen died suddenly, at New Harmony, Indiana, on the 31st of March. He was born in Lanarkshire, Scotland in 1810 and was nearly three years younger than his brother, David Dale Owen, who died about 30 years since. With his father and brother, he came to New Harmony in 1828. He served under General Zachary Taylor, as captain in the Mexican war, during the years 1847–48. In 1849 he joined his brother in the geological survey of Minnesota, and also became Professor of the Natural Sciences at Nashville; and while there, in 1857, published "A Key to the Geology of the Globe." In 1859, he was associated with his brother in the survey of Indiana, the report on which by him, appeared in 1862, after the death of his brother, and also after his having joined in the Civil War. During the year 1861, he was made Lieutenant Colonel of the 15th Indiana Volunteers, and in the autumn of that year colonel of the 60th regiment. In November of 1865 he resigned his commission as colonel at New Iberia, Louisiana (as stated in volume xlii of this Journal, 1866), and having heard of the rock salt deposit of La Petite Anse, 12 miles distant, went and investigated it, and made the first report on it to the Academy of Sciences at St. Louis. In 1865, he became Professor of the Natural Sciences in the Western Military Institute of Kentucky (afterward, changed to the University of Nashville), and held the position until the autumn of 1879. Professor Owen also devoted himself in later years to meteorology.

Professor Owen's Key to the Geology of the Globe, of 1857, exhibits the man in his science, which while practical, tended strongly toward the speculative, and also in his relations to young students, who, from his deep interest in them, drew out some pages of advice on temperance and other virtues.

APPENDIX.

ART. LI.—*Distinctive Characters of the order Hallopoda;* by O. C MARSH.

IN 1877, the writer described a small reptile from the Jurassic of Colorado, and referred it to the *Dinosauria*.* On further investigation, it was found to be distinct from all the known members of that group, and in 1881, it was made the type of a new sub-order, the *Hallopoda*.† One of the most distinctive characters, which separated it widely from all known Dinosaurs, was seen in the tarsus, which had the calcaneum much produced backward. This feature, in connection with the greatly elongated metatarsals, suggested the generic name *Hallopus*, or leaping foot.

The general structure of the pelvis, especially of the ilium and pubis, as well as the proportions of the entire hind limb, suggested an affinity with *Compsognathus*, from the Jurassic of Bavaria, and the writer, in his classification of the Dinosaurs, in 1882, placed the *Hallopoda* next to the sub-order *Compsognatha*, which belongs in the great group of carnivorous Dinosaurs, the *Theropoda*.‡

Quite recently, the writer has reëxamined the type specimen, and had various parts of it uncovered, so far as the hard matrix of red sandstone would permit. This has brought to light other portions of the skeleton, so that now many of the more important characters of the order can be determined with certainty.

In its present condition, the specimen shows both the fore and hind limbs in good preservation, portions of the scapular arch, and apparently the entire pelvis, and sacrum, various vertebræ, ribs, and other parts of the skeleton. It is at present doubtful if any portions of the skull are sufficiently well preserved for determination.

* This Journal, vol. xiv, p. 255, September, 1877.
† Ibid, vol. xxi, pp. 422, 423, May, 1881.
‡ Ibid., vol. xxiii, p. 85, January, 1882.

In size, the animal was about as large as a rabbit, but the fore limbs were proportionately much smaller. As the present specimen is the only one known, it is important to place on record its distinctive characters.

The scapula is of moderate length, and its upper portion broad and thin. The humerus is slender, with a strong radial crest. The shaft is very hollow, with thin walls, and the cavity extends almost to the distal end. The latter is but little expanded transversely. The radius and ulna are short, and were closely applied to each other. There were but four digits in the manus, the first being short and stout, and the others slender.

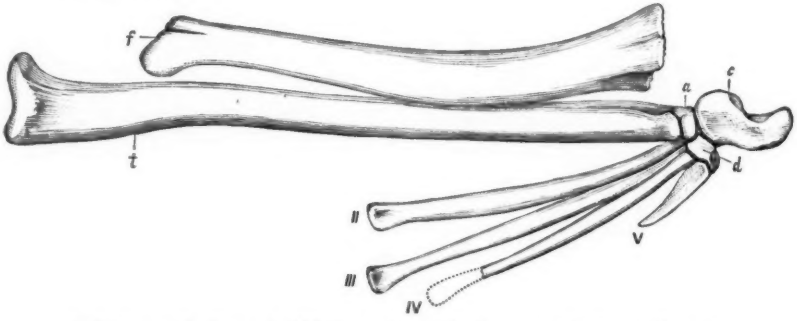
All three pelvic bones aided in forming the acetabulum, as in typical Dinosaurs. The ilia are of the carnivorous type, and resemble in form those of *Megalosaurus*. The pubes are rod-like, and projected downward and forward. The distal ends are closely applied to each other, but not materially expanded, and in the present specimen are not coössified with each other. The ischia projected downward and backward, and their distal extremities are expanded, somewhat as in the *Crocodilia*.

The femur is comparatively short, with the shaft curved and very hollow. The tibia is nearly straight, much longer than the femur, and its shaft equally hollow. The fibula was slender and complete, but tapered much from above downward. Its position was not in front of the tibia below, as in all known Dinosaurs, but its lower extremity was outside, and apparently somewhat behind, the tibia.

The astragalus is large, and covered the entire end of the tibia, but was not coössified with it. The calcaneum is compressed transversely, and much produced backward. It was closely applied to the outside of the astragalus, and although agreeing in general form with that of a crocodile, strongly resembles the corresponding bone in some mammals. The tarsal joint was below the astragalus and calcaneum. There appears to be but a single bone in the second tarsal row, although this may be composed of two or more elements.

There were but three functional digits in the hind foot, and their metatarsals are greatly elongated. The first digit was entirely wanting, and the fifth is represented only by a remnant of the metatarsal. The posterior limbs, as a whole, were especially adapted for leaping, and are more slender than in almost any other known reptile.

The main characters of the posterior limbs are shown in the figure below, which represents the bones of the left leg and foot, natural size, in the position in which they lay when uncovered. All the bones figured are still firmly embedded in the matrix.



Left leg and foot of *Hallopus victor*, Marsh; natural size; side view. *a*, astragalus; *c*, calcaneum; *d*, tarsal; *f*, femur; *t*, tibia; II, second metatarsal; V, remnant of fifth metatarsal.

There are but two vertebræ in the sacrum. The other vertebræ preserved have their articular faces bi-concave. The chevrons are slender and very elongate.

Taken together, the known characters of *Hallopus* indicate Dinosaurian affinities rather than those of any other group of reptiles, and if the *Dinosauria* are considered a sub-class, the *Hallopoda* at present may be regarded as an order of Dinosaurs standing more apart from typical forms than any other.

The characters which now indicate the position of the *Hallopoda* among the *Reptilia*, living and extinct, are given below. The discovery of more perfect specimens, however, especially of the skull, must be awaited before their nearer affinities can be determined.

DINOSAURIA?

Order HALLOPODA (Leaping Foot). Carnivorous.

Feet digitigrade, unguiculate. Fore limbs very small, with four digits in manus. Hind limbs very long, with three digits in pes, and metatarsals greatly elongated. Calcaneum much produced backward. Vertebræ and limb bones hollow. Two vertebræ in sacrum. Acetabulum formed by ilium, pubis, and ischium. Pubes rod-like, projecting downward, but not coössified distally. No post-pubis. Ischia with distal ends expanded, meeting below on median line.

New Haven, Conn., April 21st, 1890.

ART. LII.—*Additional Characters of the Ceratopsidæ, with notice of New Cretaceous Dinosaurs;* by O. C. MARSH. (With Plates V–VII.)

THE gigantic horned Dinosaurs from the Laramie, which have already been described by the writer, in this Journal,* are still under investigation, and many new points in their structure have recently been brought to light. Some of these are here placed on record for the first time, and taken in connection with those previously made known by the writer, indicate that the group is a very distinct one, worthy to be called a sub-order, which may be termed the *Ceratopsia.*

Some of the main characters of this group are shown in the specimens figured in the accompanying plates, and others will be fully represented in the illustrations of the memoir now in preparation.

The new forms described make it still more evident that the Cretaceous Dinosaurs, of which so little has hitherto been known, are quite as remarkable as their allies from the Jurassic.

Skull of Triceratops.

In addition to the armature of the skull of *Triceratops*, already described, another ossification has been found attached to the lower extremity of the jugal bone. This is a separate element, like the epoccipital bones, but in very old animals, it is coössified with the jugal, on which it rests. The external surface is rugose, indicating that it was covered with horn. It formed an anterior extension of the lateral series of ossifications on the squamosal, and served to protect the side of the head. This element may be called the epijugal bone. Its form and position are shown in Plate V, fig. 1, *d.*

The pterygoid bones and their position have already been described by the writer. The palatine bones are much smaller than the pterygoids. They are vertical, curved plates, outside, and in front of the pterygoids, and uniting firmly with the maxillaries. The vomers join the pterygoids in front, where they appear as thin bones, closely applied to each other.

* This Journal, vol. xxxvi, p. 477, December, 1888; vol. xxxvii, p. 334, April, 1889; vol. xxxviii, p. 173, August, 1889, p. 501, December, 1889; and vol. xxxix, p. 81, January, 1890.

The transverse bones give a weak support to the maxillaries, which are strengthened by close union with the pterygoids. They meet the pterygoids behind, and the palatines in front.

The Brain.

The brain of *Triceratops* appears to have been smaller in proportion to the entire skull, than in any known vertebrate. Its position and relative size are shown in Plate V, fig. 1, *f*. A side view of the brain-cast of another specimen is shown in Plate V, fig. 2, one-half natural size.

The position of the brain in the skull does not correspond to the axis of the latter, the front being elevated at an angle of about thirty degrees, or somewhat more than is indicated in Plate V, fig. 2.

The brain-case is well ossified in front, and in old animals, there is a strong septum separating the olfactory lobes.

Rostral Bone.

This bone, which has already been described by the writer, is well shown in Plate V, figs. 3, 4 and 5. Although firmly coössified with the premaxillaries in this specimen, the suture uniting them is quite distinct. In this species, the rostral bone is very large, and unusually sharp in front. The pre-dentary bone that meets it below is also very sharp, with corresponding massive dimensions.

Nasal Horn-core.

This protuberance is a separate ossification, and is free in young animals. It varies much in shape and position, in different species. In *Triceratops prorsus*, it is directed nearly forward, as shown in Plate V, figs. 3 and 4. In adult animals, it unites with the nasals, and slightly with the premaxillaries, and in old animals, the suture is entirely obliterated, as in the present specimen.

Teeth of Triceratops.

The teeth of *Triceratops* and its near allies are very remarkable in having two distinct roots. This is true of both the upper and lower series. These roots are placed transversely in the jaw, and there is a separate cavity, more or less distinct, for each of them. One of these teeth from the upper jaw is shown in Plate VI, figs. 1–4.

The teeth form a single series only in each jaw. The upper and lower teeth are similar, but the grinding face is reversed, being on the inner side of the upper series, and on the outer side of the lower series. The sculptured surface in each series is on the opposite side from that in use.

The teeth in this family are entirely confined to the maxillary and dentary bones. The rostral bone, the premaxillaries, and the pre-dentary, are entirely edentulous.

Cervical Vertebræ.

The atlas and axis of *Triceratops* are coössified with each other, and at least one other vertebra is firmly united with them. These form a solid mass, well adapted to support the enormous head.

The cup for the occipital condyle is nearly round, and very deep, as shown in Plate VI, fig. 6, *a*. In fig. 5, the same specimen is shown, seen from the side, with the fourth vertebra in position, but free. In this specimen, the rib of the second vertebra is coössified with it. On the fourth vertebra, the rib had a free articulation.

Scapular Arch and Limbs.

The scapula is massive, especially below. The shaft is narrow, sigmoid above, with a thin edge in front, and very thick posterior margin.

The humerus is large and robust, and similar in form to that of *Stegosaurus*. It is nearly as long as the femur in one individual, proving that the animal walked on all four feet. The radius and ulna are comparatively short and stout, and the latter has a very large olecranon process. The digits were terminated by broad hoof-like phalanges, one of which is shown on Plate VI, figures 7–9.

The femur is short, with the great trochanter well developed. The shaft is comparatively slender, and the distal end much expanded. The tibia is of moderate length, and resembles that of *Stegosaurus*. In one individual, at least, the astragalus is firmly coössified with the distal end of the tibia, as in *Stegosaurus*. The limb bones and other parts of the skeleton are nearly or quite solid.

The Pelvis.

The pelvis in this group is very characteristic, and the three bones, ilium, ischium, and pubis, all take a prominent part in forming the acetabulum. The relative size and position of these are shown in Plate VII, fig. 1, which represents the pelvic elements as nearly in the same plane as their form will allow, while retaining essentially their relative position in life.

The ilium is much elongated, and differs widely from that in any of the known groups of the *Dinosauria*. The portion in

front of the acetabulum forms a broad, horizontal plate, which is continued backward over the acetabulum, and narrowed in the elongated, posterior extension. Seen from above, the ilium, as a whole, appears as a nearly horizontal, sigmoid plate. From the outside, as shown in the figure, the edge of this broad plate is seen.

The protuberance for the support of the pubis is comparatively small, and elongated. The face for the ischium is much larger, and but little produced. The acetabular face of the ilium is quite narrow.

The pubis is massive, much compressed transversely, with its distal end widely expanded, as shown in the figure. There is no post-pubis. The pubis itself projects forward, outward, and downward. Its union with the ilium is not a strong one, and is similar to that seen in the pubis of *Stegosaurus*, as represented in the diagram on Plate VII, fig. 2.

The ischium is smaller than the pubis, but more elongate. Its shaft is much curved downward and inward, and in this respect, it resembles somewhat the corresponding part of the pubis of the ostrich. There is no indication that the two ischia met closely at their distal ends, and they were probably united only by cartilage.

A comparison of this pelvis with that of *Stegosaurus* shows some points of resemblance, but a wide difference in each of the elements. The pubis corresponds very closely, in its essential features, to the pre-pubis of *Stegosaurus*, but the post-pubis is entirely wanting in the specimen figured.

The characters which separate the *Ceratopsia* from the other known orders of the *Dinosauria* may be briefly stated, as follows:

(1) The skull surmounted by massive horn-cores.
(2) A rostral bone forming a sharp, cutting beak.
(3) The teeth with two distinct roots.
(4) The anterior cervical vertebræ coössified with each other.
(5) The pubis projecting in front, and no post pubis.

There are various other characters, more or less distinctive, but not of ordinal importance.

For the discovery of the specimens here described, belonging to this order, science is mainly indebted to the writer's able assistant, J. B. Hatcher, whose genius has done so much to bring to light the rare fossil vertebrates of the West.

New Cretaceous Dinosaurs.

Triceratops sulcatus, sp. nov.

One of the largest skulls of *Triceratops* secured during the past season was not in good preservation, although nearly the whole was recovered, and with it various vertebræ and other portions of the skeleton. The animal was fully adult, as shown by the ossification of the epoccipital and epijugal bones with the portions of the skull on which they rest. The epijugal bones are especially prominent and rugose, and the sutures uniting them with the jugals are nearly obliterated.

The most distinctive character of the skull is seen in the horn-cores of the frontal region, which are very large and elongate. On the posterior surface of the upper half of each horn-core, there is a deep groove, which has suggested the specific name. The horn-cores are narrow in front, and in the upper portion become distinctly ridged.

The antero-posterior diameter of the horn-cores at the base is about nine inches, and above, where the groove begins, about four and a half inches.

The caudal vertebræ in this species are unusually short, and the median caudals have a deep longitudinal groove on the bottom of the centra.

This type specimen was found in the Ceratops beds, in Wyoming, by Mr. J. B. Hatcher.

Trachodon longiceps, sp. nov.

In the same horizon with the *Ceratopsidæ*, remains of other gigantic Dinosaurs are found, but as yet only detached portions of the skull and skeleton have been secured. One of the largest of these specimens is a right dentary bone, nearly perfect, which surpasses in size the corresponding part of any of the *Ceratopsidæ* hitherto found. This dentary bone is fairly well preserved, and now measures over thirty-eight inches in length. When complete, it must have been fully three and one-half feet long. The front part, extending back eighteen inches, is edentulous. The alveolar portion is of equal length, and the border shows depressions for fifty-one teeth in a continuous series. These teeth had only a single root, and in general form, resemble those of *Hadrosaurus*. On the outer side of this dentary bone, there is a strong, rounded ridge, extending from the base of the coronoid process to the front, as now preserved. The dentary bone, as a whole, is slender, quite unlike any hitherto described, and represents a well-marked species.

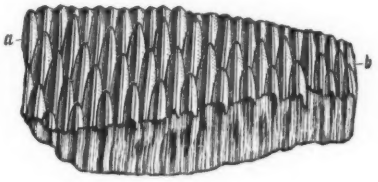
The type specimen of the present species was found by Mr. J. B. Hatcher, in the Laramie of Wyoming.

Hadrosaurus breviceps.

Additional remains of the present species, or one nearly allied to it, have been secured since the description of the type specimen.* The latter has now been completely removed from the matrix, and on comparison with more perfect material proves to be a portion of the right dentary bone. The remarkable character of the teeth is well shown in the cuts below, figures 1 and 2.

There were at least five distinct series of teeth in place at once, but only two or three rows were in use at the same time.

1.



2.

FIGURE 1.—Portion of right dentary of *Hadrosaurus breviceps*, Marsh; side view; one-fourth natural size.

FIGURE 2.—The same; seen from above. *a*, anterior; *b*, posterior.

Claosaurus agilis, gen. nov.

The small dinosaur described by the writer, in 1872, as *Hadrosaurus agilis*,† proves on investigation to represent a distinct genus, which may be called *Claosaurus*. The remains of this reptile were found by the writer, in the Pteranodon beds of the Cretaceous, near the Smoky Hill River in western Kansas. After the species was described, the writer again visited the locality, and secured other portions of the skeleton, so that now the more important parts are available for comparison.

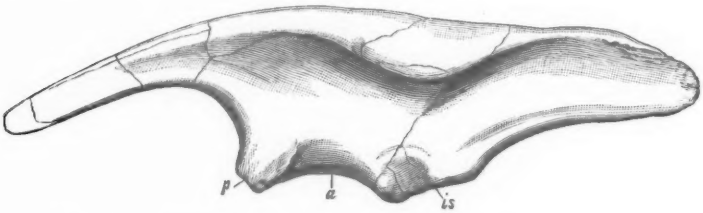
The teeth are of the *Hadrosaurus* type, but, apparently, only a single row was in use at one time. The cervical vertebræ are very short, and strongly opisthocœlian. The fore limbs were very small. There are seven vertebræ in the sacrum, firmly coössified. The caudals are longer than wide, and the tail was quite elongate.

* This Journal, vol. xxxvii, p. 335, April, 1889.

† Ibid., vol. iii, p. 301, April, 1872.

The astragalus was closely applied to the end of the tibia, but not coössified with it. The fibula is strong and complete, with both ends nearly equal in size. There were three functional digits in the pes, with their metatarsals moderately elongate. The terminal phalanges are broad, and ungulate in form.

The ilium is intermediate in form between that of *Hadrosaurus* and *Stegosaurus*, and its general characters are shown in the cut below. The portion in front of the acetabulum is very slender, and elongate. The face for the pubis is much smaller than that for the ischium.



Ilium of *Claosaurus agilis*, Marsh; side view; one-sixth natural size. *a*, acetabulum; *is*, surface for ischium; *p*, surface for pubis.

The present genus is very distinct from *Nodosaurus*, which was described by the writer from a higher horizon of the Cretaceous. The present animal had apparently no dermal armor, and was of much more slender proportions. When alive, it was probably not more than fifteen feet in length.

The American Cretaceous Dinosaurs now known represent several well-marked families, which may be arranged as follows:

Order *Theropoda*. Carnivorous.

(1) The *Dryptosauridæ*, including the large carnivorous forms, of which only imperfect specimens have been found, but sufficient to indicate that they are distinct from the *Megalosauridæ* of the European Jurassic. Limb bones hollow. Fore limbs very small. Feet digitigrade, with prehensile claws.

Order *Ornithopoda*. Herbivorous.

(2) The *Trachodontidæ*, herbivorous forms of large size, with teeth of the *Hadrosaurus* type, in many rows. Cervical vertebræ opisthocœlian. Limb bones hollow. Fore limbs small. Feet digitigrade.

(3) The *Claosauridæ*. Only a single row of teeth in use. Cervical vertebræ opisthocœlian. Limb bones solid. Fore limbs small, and feet ungulate.

(4) The *Ornithomimidæ*. Limb bones hollow. Fore limbs very small; hind limbs of avian type. Feet digitigrade, and unguiculate.

Order *Ceratopsia*. Herbivorous.

(5) The *Ceratopsidæ*, highly specialized forms fully defined above.

(6) The *Nodosauridæ*. Heavy dermal armor. Bones solid. Fore limbs large. Feet ungulate.

No *Sauropoda* are known from the American Cretaceous.

New Haven, Conn., April 22d, 1890.

EXPLANATION OF PLATES.

PLATE V.

FIGURE 1.—Skull and brain-cast of *Triceratops flabellatus*, Marsh; seen from above; one-twentieth natural size.

c, supra-temporal fossa; *d*, epijugal bone; *e*, epoccipital bone; *f*, brain-cast; *h*, horn-core; *h'*, nasal horn-core; *n*, nasal bone; *p*, parietal; *r*, rostral bone; *s*, squamosal.

FIGURE 2.—Brain-cast of *Triceratops serratus*, Marsh; side view; one-half natural size.

c, cerebral hemispheres; *cb*, cerebellum; *m*, medulla; *ol*, olfactory lobe; *on*, optic nerve; *p*, pituitary body.

FIGURE 3.—Anterior part of skull of *Triceratops prorsus*, Marsh; side view; one-eighth natural size.

FIGURE 4.—Front view of same.

FIGURE 5.—The same; seen from below.

h', nasal horn-core; *n*, nasal bone; *na*, narial aperture; *pm*, premaxillary; *r*, rostral bone.

PLATE VI.

FIGURE 1.—Maxillary tooth of *Triceratops serratus*, Marsh; outer view; natural size.

FIGURE 2.—The same tooth; side view.

FIGURE 3.—The same tooth; inner view.

FIGURE 4.—The same tooth; seen from below.

FIGURE 5.—Anterior cervical vertebræ of *Triceratops prorsus*, Marsh; side view; one-eighth natural size.

FIGURE 6.—The same; front view.

a, anterior face of atlas; *d*, diapophysis; *p*, posterior face of fourth vertebra; *r*, rib; *s*, neural spine of axis; *s'*, neural spine of third vertebra; *s''*, neural spine of fourth vertebra; *z'*, posterior zygapophysis.

FIGURE 7.—Ungual phalanx of *Triceratops horridus*, Marsh; front view; one-fourth natural size.

FIGURE 8.—The same bone; side view.

FIGURE 9.—The same; posterior view.

PLATE VII.

FIGURE 1.—Pelvis of *Triceratops flabellatus*, Marsh; side view; one-twelfth natural size.

FIGURE 2.—Pelvis of *Stegosaurus stenops*, Marsh; side view; one-tenth natural size.

a, acetabulum; *il*, ilium; *is*, ischium; *p*, pubis; *p'*, post-pubis.

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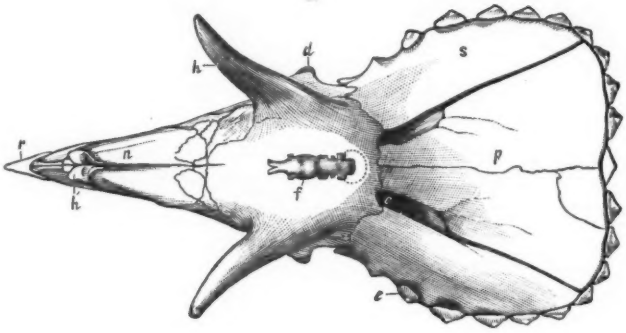

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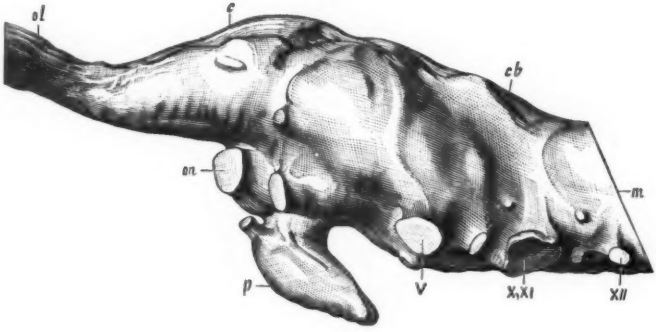

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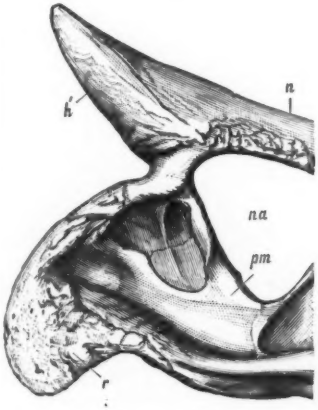

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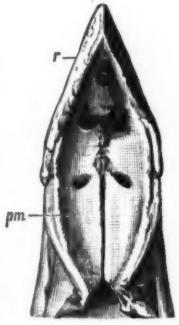

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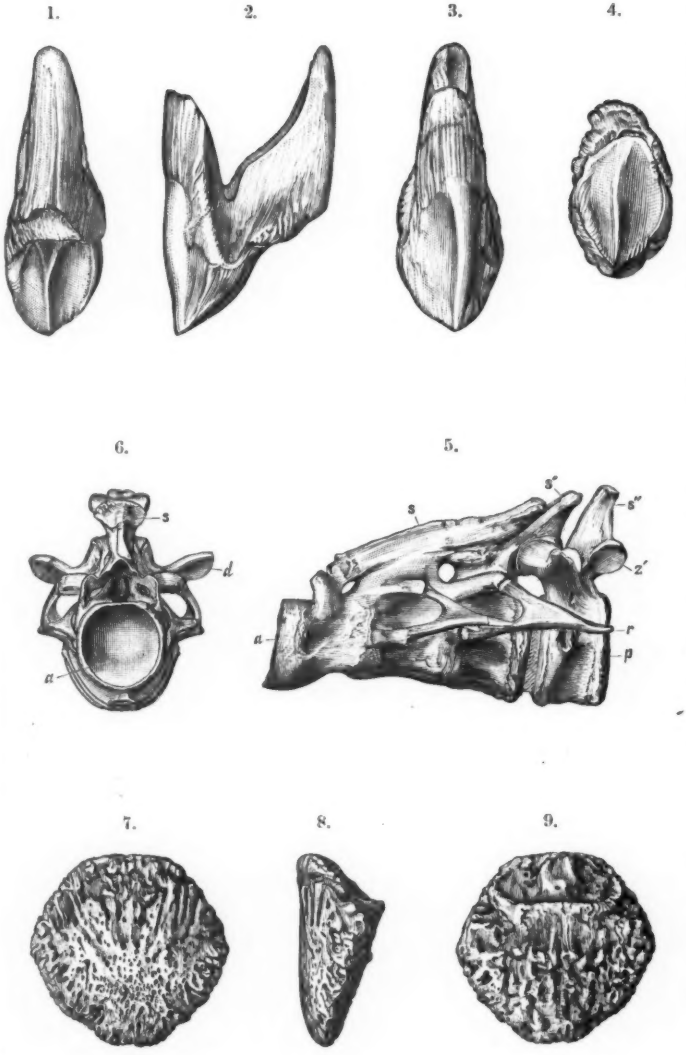

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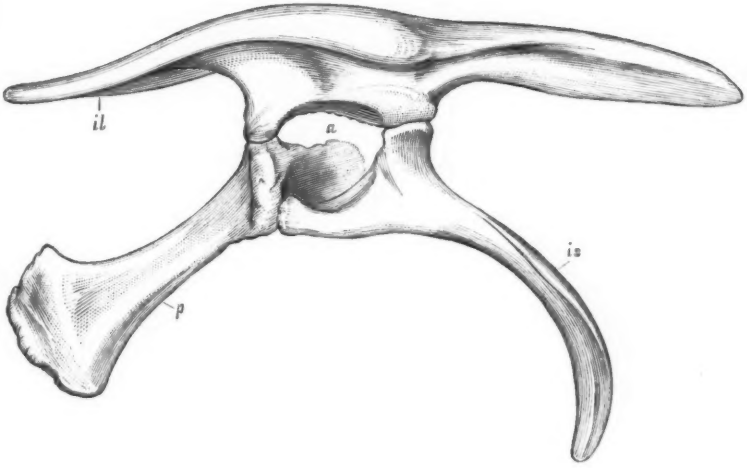

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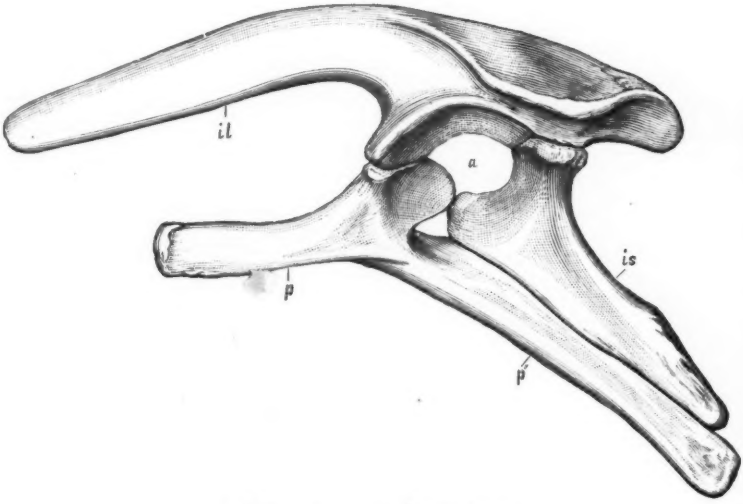

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